AN INTRODUCTION TO
GENERAL SCIENCE

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BY

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GEORGE G. HARRAP & CO. LTD.
LONDON BOMBAY SYDNEY

First published 1936
by George G. Harrap & Co. Ltd.
182 *High Holborn, London, W.C.1*

MADE IN GREAT BRITAIN. PRINTED AT THE PITMAN PRESS, BATH

PREFACE

For the last twenty years the writer has been responsible for the organization of courses in General Science. The ages of his pupils range from eight to nineteen years, and in the Junior School, where the ages are from eight to eleven years, the lessons are drawn from as wide a field as possible. "The world is my parish," translated into pedagogical terms, means that the whole realm of Nature is now recognized as the domain, or at least the hunting-ground, of the science master, in spite of occasional fulminations of teachers of history, geography, and some other subjects. To justify this attitude take as an illustration the study of iron. This topic is not a monopoly of the chemist, but may legitimately form the material of a lesson in chemistry, physics, history, or geography. The chemist is interested in the ores of iron and the method of extracting the metal from them, in its conversion into steel, and in its compounds with other elements; the physicist studies its magnetic properties; the history master may refer to the Iron Age and the development of weapons, tools, armour, etc.; while the geography master considers the geographical distribution of the metal and its influence on human relations. But it is impossible for any one of them to keep within watertight compartments, and it is highly undesirable that teachers should attempt to do so. Several chapters in this book may be criticized as being history or geography rather than science, but the writer has deliberately included these

subjects in his course, not only for the reason stated above, but also to show that science has deep human interests. Chemistry, physics, and, to a lesser degree, biology are fundamental to the study of nearly everything in the universe.

The course starts off with the story of a great discovery. It shows a great pioneer, obeying some urge within him, ever facing difficulties, dangers, physical and mental suffering, and sometimes ingratitude, jealousy, and imprisonment, in pursuit of his end. One cannot, however, embark on the work of discovery without adequate preparations, and the course provides what is believed to be a sound training, especially in the basic principles of physics, chemistry, and biology. While the knowledge acquired is valuable in itself, it is hoped that the pupil will gain also an insight into the method of scientific discovery.

Theoretically, the course should be progressively difficult, but this ideal is not always attainable even in studying formal chemistry and physics; it is less possible of attainment in a course which includes the beginnings of several sciences. The mountaineer after a strenuous climb often has his period of relaxation before the next ascent; and a chapter which has tested the capacity and courage of the pupil to the full may with advantage be followed by something in the nature of a relief.

The book is a combination of descriptive and experimental work, and the experiments are of three kinds: firstly, a repetition of certain experiments that the teacher has already performed, to enable the pupil to learn a sound technique; secondly, experiments which enable him to acquire confidence and manipulative skill, as well as gain valuable information which may

be the starting-point of future lessons; thirdly, experiments in really new discovery which can be safely undertaken by all who have thoroughly mastered the preceding chapters. Many experiments combine more than one of these qualifications. In some cases a teacher using the book may think that the instructions to the pupil are too full, in that they tell him things that he ought to find out for himself. But the book is a compromise between a text-book and a laboratory guide, and as it will be used mainly in classes which contain thirty or even more pupils, all supervised by one master or mistress, an absolutely safe course is essential. In addition to the "Experiments" so designated in the text are many more which are incidentally introduced, and the majority of the questions (170 altogether) at the ends of most chapters are of an experimental nature. No instructions are given with the latter, so that the pupil has abundant opportunities of exercising his initiative. Altogether about three hundred experiments can be based on the course, and most of them can be carried out with simple and inexpensive apparatus.

For many suggestions which have led to improvements in the book and a reduction in the number of errors the writer is indebted to his colleague, Mr H. P. P. Flewitt, M.A., B.Sc., and to D. D., W., G. M., and A. Fielding.

The editor of *Discovery* (published by Benn Bros., Ltd.) has kindly permitted the reproduction of two illustrations from that journal.

W. R. F.

FLEETWOOD
1935

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CHAPTER I

INTRODUCTORY

I KNOW that you are looking forward to studying science. It is rather unfortunate that many of the things that a boy or girl is keen on doing cannot be done until years after this desire comes. So I am trying to start you on your scientific career immediately, but you must realize that you cannot do the science that is taken in the higher forms. Science must be presented in a certain order. Do not expect to make nasty smells, or fires, or explosions—yet. These things are not science, although scientists in the course of their work may make, and even use, a nasty-smelling gas.

A scientist uses his senses. He sees, and touches, and smells, and listens to, and sometimes tastes things (although the last is often dangerous—do not taste things in a laboratory unless you are told that it is safe to do so), and then he thinks about his work and may reason something out, or make what we call a discovery. Are you made of the stuff of which scientists are made? Are you interested in what goes on around you? I think it was Dr Nansen—one of the brave men who wanted to know more about the lands near the North Pole—who, being asked why he was so foolish as to risk his life in those terrible regions, replied, "Man wants to know. When he ceases to want to know he ceases to be man."

But do not be curious about other people's private

affairs. Be curious about horses and cows, fishes and birds, the sun, moon, and the stars, glaciers, rivers, and the tides, etc. You are living in a wonderful world, and as you grow older you will find that there is so much to learn that you will have to leave a great many regions entirely unexplored. The great explorers of the past have explored but a small area. Dr Livingstone had only time to explore a small part of Africa, Captain Scott a small part of the land around the South Pole. It is too soon for you to say what kind of exploration you are going to engage in; but get ready, train your mind, be industrious, be keen, then some day after you have left school you may discover something which will bring credit on your parents, your school, and your country as well as on yourself.

I must warn you at the start that experimenting may prove dangerous, and you should always observe the following rules:

(1) Do not do any experiment that has not been authorized. You do not know what is going to explode or get on fire.

(2) Do not wander about the laboratory to see how some one else is getting along. Keep your eyes open and always on your work.

(3) Remember that an accident in the laboratory may cause you or some one else to lose an eye or suffer some other injury. Take great care.

(4) Whenever you go into the laboratory to carry out an experiment you have some definite object in view. This is called the 'aim of the lesson.' Unless you do what you set out to do you have failed, to some extent, in your work of discovery.

(5) As your experiment is proceeding make notes of what you observe, and state what you conclude from your experiment.

(6) When the lesson is over do not be afraid to clean the apparatus and put it carefully away. Then others following you will find it where it ought to be.

CHAPTER II

THE STORY OF A GREAT DISCOVERY

BEFORE beginning your work as a scientist it will be well to learn something about a few of the great scientists of the past. Experimenters sometimes meet with serious accidents either through their own carelessness or through something happening which they did not think would happen. So learn to be careful in doing simple experiments, and later you will be able to perform the more difficult ones with safety and success.

Hundreds of years ago experimenters and philosophers were often in danger of losing their lives for another reason: people thought that they were in communication with evil spirits. Many a brave scientist has been burned at the stake because of his discoveries and inventions, although we are all making use of them now. One does not mind being laughed at. The man who invented the umbrella was laughed at when he began to use it; so were the men who talked of flying, yet by sticking at their work and ignoring the ridicule of ignorant people they succeeded in developing the aeroplane.

Sometimes scientists have to be heroic in another sense. They make discoveries in which no one believes, and they have to experiment on themselves. Take the case of laughing-gas, which dentists give to their patients so that they cannot feel the pain. Sir Humphry Davy observed that this gas, when breathed, made people insensible to pain. He was brave enough

to try it on himself before he recommended its use to others. Again, when he invented the Davy lamp he went down a mine himself and showed the miners that his lamp was perfectly safe to use. I call Davy a hero. What do you think?

You may be surprised to hear me describe Columbus as a hero of science, for was he not a sailor who discovered America? I do not want you to give the word science a narrow meaning. A scientist is a person who, having examined some part of the universe, thinks about it and arrives at some new conclusion; then he tries to prove that his way of looking at things is right by performing an experiment. If you read about some of the great scientists in a book of reference you may say, "That man doesn't seem to have done much. Why should he be specially remembered?" I want to warn you not to decide that one person is greater than another by the number of, say, patents he has brought out, many of which may be of very little value. Certain men and women have found civilization in a groove, unable to move, and they have hit upon a plan to extricate it. If the plan succeeds they render an exceedingly great service to every one. The greatest scientists are the ones who pull us out of the ruts of life. Columbus was such a man, and I will tell you something about him.

Columbus was born at Genoa about the year A.D. 1447, and went to sea when fourteen years of age. He had a very exciting time, trading all over the Mediterranean, fighting pirates, and even going as far as Iceland, where, it is believed, he heard that the Northmen, under Eric the Red, had discovered America about A.D. 1000. He had been educated at

the University of Pavia, and so probably had a grounding in Latin, geography, astronomy, geometry, and drawing, besides a wide knowledge of navigation. In addition, he was a man of excellent character, being very intelligent, courageous, patient, loyal, and God-fearing. For years Columbus's mind was turning over this question: "What lies across the Atlantic?" Most people living at that time thought the earth was flat, and that if they sailed too far from land they would fall off the edge of the earth and go no one knew whither. Columbus thought this was absurd, and was willing to take the risk. He thought that the earth, the sun, the moon, and the stars were all shaped like a ball or an orange, and that a sailor who sailed on and on, say westward, would, in time, come back to his starting-point, unless land blocked his way. For years Columbus gathered information. He found that many of the Latin and Greek authors held this view. He sought out, and talked to, mariners who had sailed farthest into the Atlantic. Some had picked up, after west winds had been blowing several days, hundreds of miles west of Spain pieces of wood curiously carved; also huge canes which were unknown in Europe, but which, from the description of them, we now know must have come from the Indies. Columbus believed that he could find a new way to India, where the Mohammedans would not be able to interfere with the trade of the Christians.

But he had not the money to carry out his big test. First of all he went back to Genoa and asked his own countrymen to help him. They refused. Then he went to the King of Portugal. Portugal was his second home, for he had lived there many years and had

married a Portuguese lady; also the Portuguese had been for several years, and were still, engaged in great works of exploration. A council was called to consider the proposal, but it was condemned—yet the King secretly dispatched a caravel for the Cape Verde Islands with instructions to find this new way to India if possible. Soon the expedition returned and reported that the proposal was a madcap scheme. Henry VII of England was unable to help him—but Cabot was sent out on an expedition to America a few years later. Much of Columbus's travelling had to be done on foot. His wife was dead, and his only companion was his boy.

One day, footsore and hungry, he called at a convent just outside the little port of Palos, in Andalusia, and begged for bread and water. The Prior listened wonderingly as he told his story, and was so impressed by it that he sent him to Cordova, where the King and Queen of Spain, Ferdinand and Isabella, held their Court. Months dragged on, and Columbus became so poor that he had to make maps and charts for a living. The Spanish army was busy driving the Moors out of Spain, and we must not blame the King and Queen unduly for their delay. Later a council of theologians, geographers, and mathematicians was held at Salamanca, and Columbus was invited to explain his proposal, those present trying their best to pull his arguments to pieces. Some of them used an argument similar to some which are still used to-day: "How is it possible, since so many thousands of years have passed since the creation of the world and skilful mariners have never found countries to the west, that Columbus should have more knowledge than they?" Others

tried to frighten him by saying that even if the earth were like a ball a ship would be unable to climb its way back again over the sea, though a strong wind were helping it.

He returned to his friends at the convent disappointed. Many people really thought that Columbus was mad, and it is said that children used to touch their foreheads when they saw him because they had been taught by their parents that he was insane. Some people are fond of saying what they would do if they had opportunities; they would startle the world or make some staggering discovery. Columbus tried for eight years to get some one to help him to fit out an expedition. At last his friend, the Prior, persuaded Queen Isabella to take an interest in the enterprise. Even when money and ships were found sailors would not venture, as they were afraid of some catastrophe overwhelming them in the Atlantic. At length Martin Pinzon and his brother volunteered, and soon afterwards three ships, the *Santa Maria*, the *Pinta*, and the *Nina*, commanded respectively by Columbus and Martin and Vincent Pinzon, were ready for sea. The three crews numbered only ninety men, many drawn from the prisons, on account of the difficulty of getting volunteers.

Before sunrise on Friday, August 3, 1492, they set sail. They made for the Canaries, where there was a delay of three weeks owing to repairs to the *Pinta's* rudder, which Columbus thought had been damaged by some of the crew who were really afraid to go farther. On September 4 they resumed their course, and in a few days fresh breezes carried them out of sight of land. For weeks Columbus had to use every

resource to cheer up his men, and to make it appear that they had not gone very far from home he kept two ship's logs, a false one to show to the crew and an accurate one that he kept to himself.

They were always on the look-out for signs of land, not only because they were afraid of the sea, but also because the King and Queen of Spain had promised a reward of thirty crowns to the one who first saw land. At one time they saw a flock of birds and the sea was covered with weeds, which the sailors thought would enmesh them. Columbus said they indicated that land was near, so the sounding-rod was thrown out, but it failed to touch the bottom. The crews sometimes became mutinous. "With some he reasons; others he allures with hopes; the rest he keeps in awe by dread of instant chastisement." On September 25 they were so sure that they could see land that they fell upon their knees and praised God, and the strains of *Gloria in Excelsis* were wafted on the wings of the breeze. All night they pursued their eager way, but when morning dawned they found that they had mistaken clouds for land.

The captains now compared their reckonings from the Isle of Ferro. The pilot of the *Nina* said they had sailed 540 leagues; he of the *Pinta* said 634; Columbus gave it out to be 584, but according to his private reckoning he knew it was 707. On October 7 the *Nina* fired her signal gun announcing 'land'; again it dissolved into clouds. It would have been difficult to have kept the crews in order much longer, but a few days later surer signs of land began to appear. The *Santa Maria* noticed green rushes floating by, and fishes whose usual haunts are the rocks; the *Pinta*

picked up a cane, a curiously worked staff, a small board, and weeds freshly torn from the rocks; while the *Nina* secured a branch of a thorn, newly broken off and bearing red berries. At ten o'clock in the evening of October 11 Columbus fancied that he saw a light, and he was supported by several others. But he did not make any announcement so as not to disappoint his men again. However, at two in the morning the *Pinta* fired her gun, to announce that they had reached their goal; and when morning dawned they saw a fair green island stretching before them.

Men from each ship went ashore, and after devoutly giving thanks to God for His mercies Columbus claimed the land for Spain and planted the Spanish flag on one of the islands now known as the Bahamas. He gave it the name of St Salvador. His men crowded round him, vying with each other as to who should pay him most honour, and beseeching him to overlook their mutiny. Thinking he was near the shores of India he called the inhabitants Indians. Then he sailed in and out of what we now call the West Indies, discovering Cuba, Haiti, etc. But here we must take leave of him for the present.

Through disobedience his own ship was wrecked, and he had to sail home in the *Nina*. He set sail on January 4, 1493, and after a terrible voyage reached Spain on April 15, 1493. As was to be expected, he became a great hero, and the Indians who accompanied him were objects of much curiosity. Later he made several other voyages to the Indies, meeting difficulties, enduring hardships, and securing for his reward jealousy and ingratitude. He died almost penniless, but—he had discovered America.

EXERCISES

1. Who was Vasco da Gama?

2. Who was the first person to sail round the world?

3. Look up in some book of reference what is said about Livingstone, Shackleton, Scott, Amundsen, and Nansen. Get a map and point out the lands they visited.

4. Discoverers are sometimes called 'pathfinders.' Is this a good name? Why?

5. Was Columbus a scientist? Give reasons for your answer.

6. What is the difference between a discoverer and an inventor? Give examples of each.

7. Herodotus, who was born in 484 B.C., tells of an Egyptian expedition which sailed down the Red Sea and reappeared from the west. Herodotus did not believe this was possible, for the sailors said they had the sun 'on their right hand' for a great part of their journey. Is it possible that the sailors were correct? If so, where would the phenomenon occur?

8. It has been said of Columbus that he discovered America "because it was in his way." Is there any merit in making discoveries of this sort? Give other examples.

9. An artist, an inventor, a discoverer, an engineer, and a person on holiday visit Niagara Falls. What would each 'see'?

10. The following quotation refers to George Stephenson:

> Engineers sneered at him, and went into the witness-box to prove how the boilers of his locomotive would burst and blow the passengers to bits, and that in any event it was quite impossible for the wheels of the train to grip the rails. Farmers were told that sparks from the chimney would destroy the crops and burn down the houses; that railways would prevent cows from grazing and hens from laying; and noblemen were warned that the poisonous air from the engine would kill their pheasants and foxes.[1]

(*a*) Were these predictions fulfilled?

(*b*) Can you give any other examples of prejudice (pre-judging)?

[1] *Man's Genius*, by E. B. Barwick (J. M. Dent and Sons, Ltd.).

CHAPTER III

FINDING THE WAY

In Chapter II we read that many of the sailors who accompanied Columbus were afraid of getting lost at sea or of falling over the edge of the supposed flat earth. Once such fears were widespread, but so carefully has the earth been mapped out that nowadays one can travel by road, rail, sea, or air with safety.

Children go over the same ground together, or with their parents, and get quite accustomed to every street, or field, or hill; then, if they are alone, they can easily find their way about. But suppose a boy or girl is exploring new ground, say, going on a ten-mile ramble. So many new roads, fields, and woods are crossed that he or she may be perplexed, if not lost. We may have read stories of people exploring dark, winding caves, who helped themselves to find their way back by fastening a piece of string at the entrance and unwinding it as they penetrated the cave. They could always find their way back by following the string. An observant person will notice something, a tree, or house, or hill, as he makes a journey, and on the return will look out for these features. On entering a pathless wood some travellers, Red Indians, for example, used to snap off branches so that they could return by the same route. If they did not intend to return that way the broken branches served as a guide to some one who might be following them—compare our paper-chases.

In the Old Testament we read that the people became so numerous that they had to find new homes farther afield. They were afraid of getting lost, so they built a tower so high that its top appeared to reach to heaven. While they could see it they knew they were not far from their old home.

It has long been known that one can see much farther from the top of a tree or hill than from the bottom. From the deck of a ship a sailor can see three or four miles in every direction, but by climbing into the rigging he can see much farther; and on climbing to the top of a hill only 1000 feet high one can see about forty miles in every direction. Sailors wrecked on an unknown shore either climbed a hill or a tall tree to see if they could learn their position.

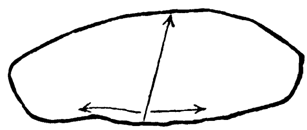


FIG. 1

People living near the sea often wondered what lay beyond it. They sailed or walked up and down the coast, sometimes venturing a little farther, but they always kept the coast or some landmark in view. In time they sailed or walked round most of the lakes and inland seas, such as the Caspian Sea, Lake Superior, and the Mediterranean Sea. Then daring adventurers, knowing that the land was in front of them, even though they could not see it, sailed across the sea (Fig. 1).

Sometimes they were swept out of their course by currents, as when Cabral, keeping a 'safe' distance away from the fever-stricken coast of West Africa, was carried to South America, which he 'discovered' in 1500.

In far-distant days there were few good roads, but

at first only well-trodden footpaths, to be followed later by the long, carefully constructed, military roads of the Romans. Travellers do not get lost on straight roads but at junctions, and some natural object at a junction would be the 'signpost' before the advent of the familiar ones of to-day. It is very easy, even in a large town, to find one's way about if certain rules are kept in mind:

(1) A person who keeps on a straight road should not get lost.

(2) On leaving the main road read the name of the street where you turn off, or notice some object—a tree, a bridge across a river, a church. There will be a link of association in your mind between the turn of the road and the tree, bridge, or church (Fig. 2).

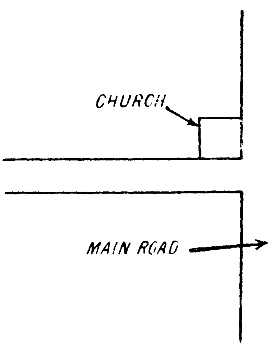


FIG. 2

The roads, forests, mountains, lakes, and rivers discovered were later represented in plans, charts, and maps, and certain signs were used in referring to these features. A bold line was often drawn to represent a mountain range; a line gradually growing thicker represented a river (Fig. 3).

FIG. 3

A map represents a large area, and so a scale is adopted, say, 100 miles actual distance is represented by only one inch on the map. Maps would be drawn in sand or on smooth rocks before they were drawn on

paper. The earliest recorded map dates back before the time of Christ.

The sun, moon, and stars were early objects of interest, and in an age when there were no artificial lights people had plenty of time to study the heavens, to observe the daily movements of the sun across the sky, to learn the many star-clusters, to notice the changing lengths of the days and the changes of season, etc. We have inherited the cardinal points—

FIG. 4

i.e., N., S., E., and W.—from the ancients, but they had to discover them for themselves.

It was observed that the sun rose in one part of the heavens and set in another, and that when it appeared to be at its hottest it was highest in the heavens.

If they had the sun on their backs when they set out on a short journey they noticed that they were facing it on their return (Fig. 4).

Herodotus had reported (see Chapter II) that sailors, before the time of Christ, had referred to the sun as being "on their right hand." We have dropped the use of such words as 'right hand' and 'left hand' in this connexion, and say that the sun rises in the east and sets in the west.

At midday to an observer in the Northern Hemisphere the sun appears to be towards the south; to an observer in the Southern Hemisphere it appears to be

towards the north. These four points, N., S., E., and W., are called the cardinal points because they are the chief points from which all the other points of the compass are derived. Fig. 5 shows the main points of the compass with respect to an observer at O. X is due

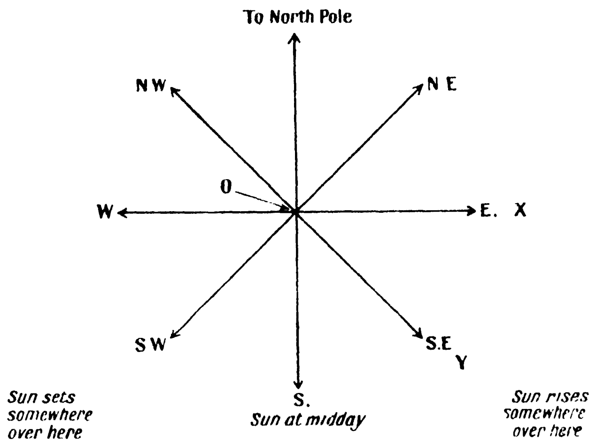
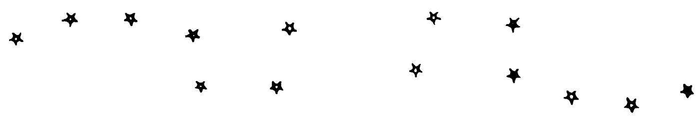


FIG. 5

east of O. Y is equally east and south of O, and is said to be S.E. of O.

The sun lights up one side of the earth by day, and when it has set we have to wait many hours before it reappears again. While it is absent from view (night) most living things (plant as well as animal) sleep. But some animals hunt during the night and sleep during the day, and travellers often have to make their journeys by night. When the moon is shining they can often find their way if they know the direction they want to go. But how can they find direction during the night? By observing the stars. It has long been known that certain stars, although they move, move together—for example, the well-known group of seven

stars named the Plough or the Great Bear. Sometimes the Plough is the right way up, as shown in Fig. 6 (i). About twelve hours later it is upside-down (Fig. 6 (ii)). But the stars keep their *relative* positions. Then a most important discovery was made. An eighth star—not a very bright one—was observed some distance away, and the seven stars appeared to revolve round it, and



(i) (ii)

FIG. 6

always to keep the same distance away from it (Fig. 7). This eighth star can be found by imagining the last two stars (called the Pointers) to be joined by a line which is produced. The eighth star is nearly on the line. It is known as the Pole Star or the Northern Star, and as it is in the true north it has been regarded as the symbol of constancy. Shakespeare makes Julius Cæsar boast:

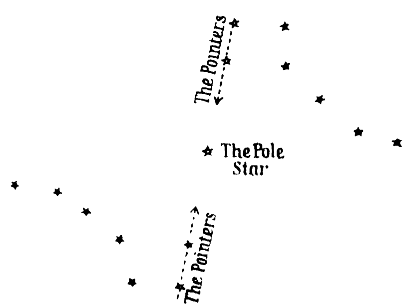


FIG. 7

> But I am constant as the Northern Star,
> Of whose true-fix'd and resting quality
> There is no fellow in the firmament.
>
> *Julius Cæsar*, Act III, Scene 1

The seven stars of the Plough form a constellation, and the imagination of the earliest observers saw pictures in this and other constellations. The Great

Bear was imagined in one or other of the ways shown in Fig. 8.

On the opposite side of the Pole Star from the Plough are five stars forming the constellation Cassiopeia (Fig. 9), which looks like the letter W or M according to the position in which you see it.

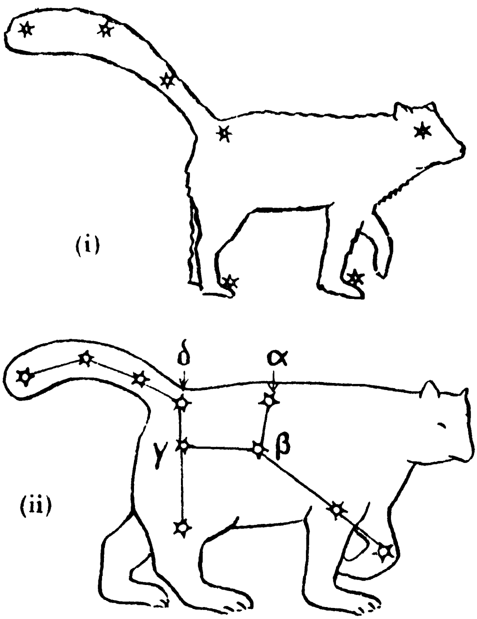


FIG. 8. THE GREAT BEAR
In (ii) α is the back of the Great Bear, β the loins, γ the thigh, and δ the root of the tail.

Fig. 10 shows how, having discovered the Plough, you may find Cassiopeia.

When the Plough is high in the heavens Cassiopeia is found low down in the north.

A third well-known and easily discovered constellation is Orion (Fig. 11), named after a great hunter celebrated in Greek mythology.

The head, two hands, belt (three stars), and two feet can readily be imagined. On the right arm is a red star named Betelgeux, which is thousands of times bigger than our sun. A brilliant, bluish-white star, named Rigel, represents a foot (Fig. 12).

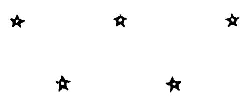


FIG. 9. CASSIOPEIA

The Plough is very useful in helping us to find other constellations (Fig. 13).

When you are able to pick out these constellations

you should buy a star-atlas, or consult one of the papers giving star-maps, and extend your knowledge of the heavens.

In the Southern Hemisphere a constellation known

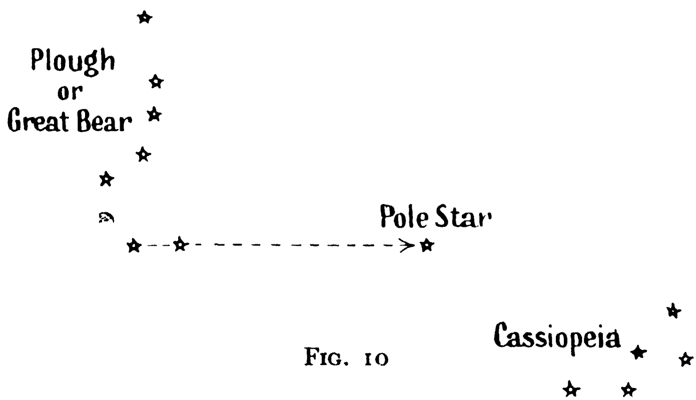


FIG. 10

as the Southern Cross (Fig. 14) is visible. Is it visible anywhere in the Northern Hemisphere?

Some of the constellations are mentioned in Homer and in the Bible, and those familiar with them used their knowledge to locate their position, roughly, at any rate. A person at the North Pole would see the Pole Star immediately overhead; a person at the equator would see it on the horizon.

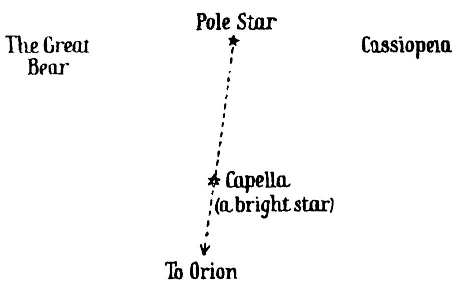


FIG. 11

In ancient times, when there were no books, cinemas, or concerts, people used to gather round the fire at nightfall to tell stories which had been handed down to them, or gaze wonderingly into the heavens, or go

to bed. They became very familiar with the 'pictures' they saw in the heavens, and knew their movements well. The Northern Star (where it was visible) was their guide, and in the absence of chart and compass might serve as an excellent guide to us.

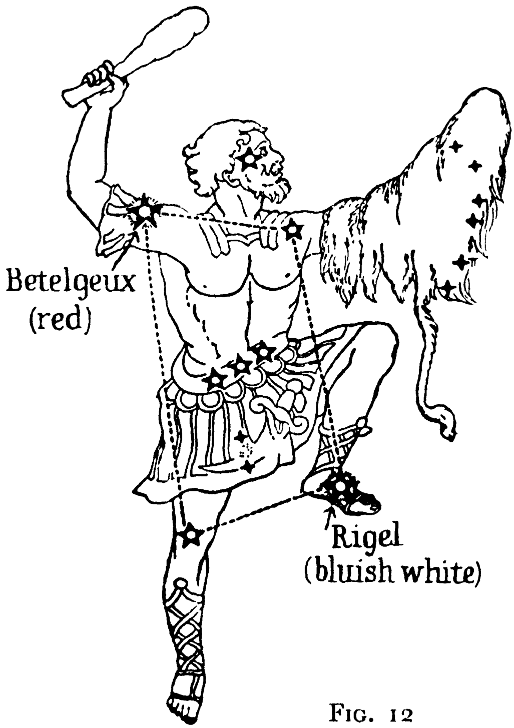


Fig. 12

One of the most important methods of finding one's way is by means of the compass, and this owes its origin to a very wonderful mineral discovered in Magnesia (Asia Minor) thousands of years ago. It picked up bits of iron, and when an iron bar was stroked with it the iron gained this same power itself. The stone (called lodestone) is a natural magnet; the stroked iron is an artificial magnet.

Experiment 1. Examine a piece of lodestone. See

if it will pick up iron filings, pins, pen-nibs. Make a drawing to show where the iron filings are distributed.

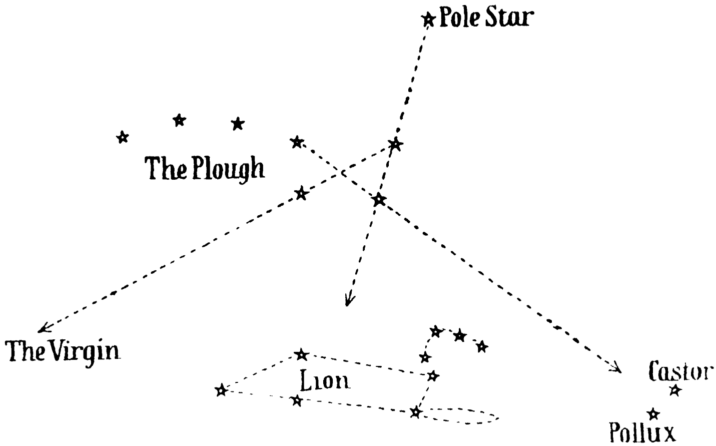


FIG. 13

Put the lodestone and the filings on one side until you have done the next experiment. How many tufts of filings are there? Make sure that every part of the lodestone has been in contact with the filings. Each tuft is at a pole.

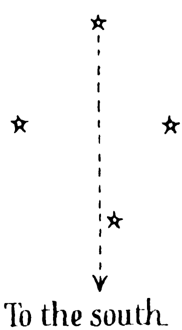


FIG. 14

EXPERIMENT 2. Lay a thin piece of iron on the bench. Stroke it with a piece of lodestone from left to right and on returning for the next stroke lift the lodestone off the bar and move it through the air as shown in Fig. 15. Instead of a piece of lodestone a bar magnet will do. Remember always to stroke the iron in the same direction. Do this ten or fifteen times. Now dip the ends of the piece of iron into iron filings. Is it a magnet? Where do the filings collect? How many poles has your magnet?

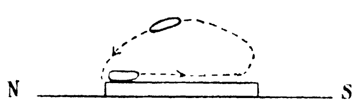


FIG. 15

Mark the positions of these poles with chalk or gummed paper.

Another great discovery was made when a piece of lodestone or a magnetized bar was suspended by a thread and allowed to come to rest. A magnetic needle may also be used—it is a small magnetized iron bar, balanced on a fine point and free to move in a horizontal plane.

EXPERIMENT 3. Suspend a bar magnet which has the N. and S. poles marked. Start it vibrating. How does it point when it comes to rest? Does it always point in the same direction?

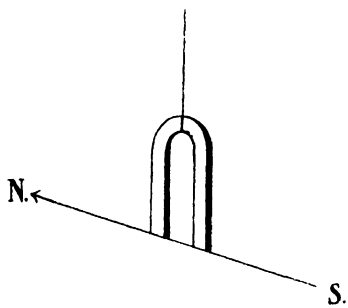


FIG. 16

EXPERIMENT 4. Hang up a horseshoe magnet by a thread (Fig. 16). Start it swinging. How does it point when it comes to rest?

EXPERIMENT 5. Float a bar magnet on a piece of cork in a dish of water (Fig. 17). How does it point when it comes to rest?

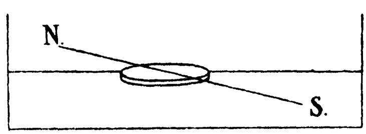


FIG. 17

In the introductory chapter it was stated that if you performed an experiment in the laboratory without coming to some conclusion you had failed in your work of discovery. You should write down your conclusion or conclusions to each experiment as follows:

Experiment 1. Lodestone is magnetic and will pick up small iron or steel objects. The iron filings collect mainly in two tufts, one at each end of the lodestone. These tufts are at the poles.

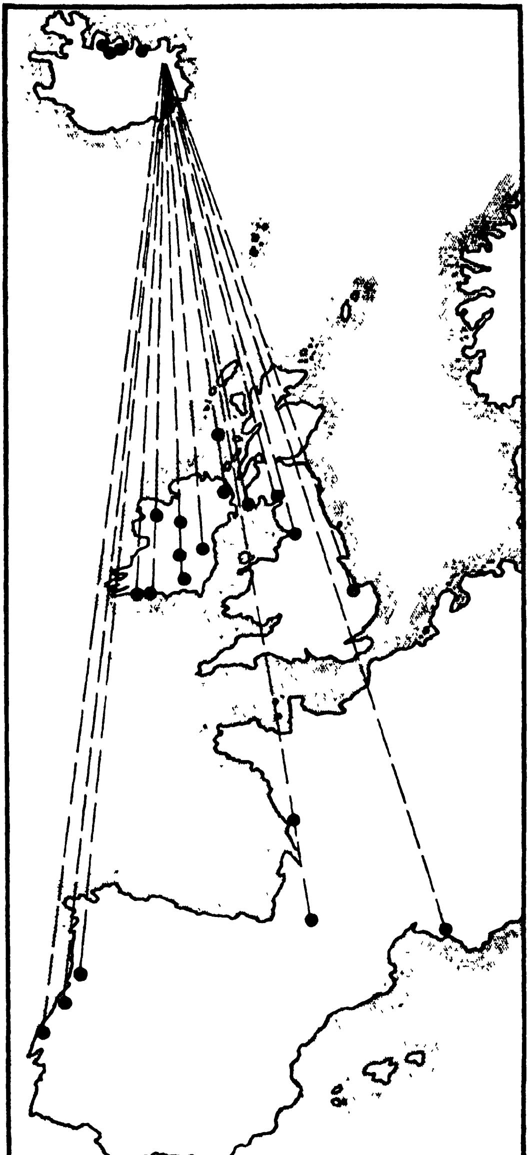


FIG. 18. RECOVERIES OF GOLDEN PLOVER

The birds found at the places indicated by a black spot were all marked in Iceland.

By kind permission of "Discovery."

Experiment 2. Lodestone can be used to magnetize a bar of iron, which in its turn can be used to magnetize other bars of iron or steel.

Magnets free to move in a horizontal plane come to rest in a definite direction, according to the position of the place on the earth's surface. The end of the magnet which points towards the north is called the north-seeking pole or simply the north pole. Do the north and south pointed out by a magnet agree with the geographical north and south found by looking at the Pole Star or at the sun at midday? If they do not agree the angle between the two directions is called the angle of declination, or the 'variation' at that place. Variations have been measured for thousands of places on the earth's surface and they help sailors and others to fix their positions at sea or in some unknown land.

From these small beginnings all sorts of discoveries and inventions, such as the compass needle, the mariner's compass, and the dynamo, have sprung.

Before concluding this chapter it may not be irrelevant to mention that birds leaving our shores in autumn for a warmer climate, or in spring for a colder one, have to find their way without compasses. How do they do it? They gather together in thousands, the experienced birds take the lead, and the young birds follow and learn the way. Then, keeping some landmark or the sea-coast in view, and the sun before or behind them, according to the direction they are taking, they are able to find their old haunts again (Fig. 18).

EXERCISES

1. On account of the earth's spherical shape we can see farther by climbing a tower or a hill. But if the earth was flat, as it was once believed to be, could you then see farther by climbing a tower? Illustrate by a drawing.

2. Letting 1 mile be represented by $\frac{1}{4}$ in., draw a line to represent a road. Find a point five miles from it. What other information would you require to fix a point with exactness?

3. Draw a circle of radius 2 in. to represent the earth. Show the equator, the tropics,and mark the Northern and the Southern Hemispheres. Also mark the Poles, and put in two lines of latitude and two lines of longitude. What do you notice about the sizes of these four circles?

4. In the Northern Hemisphere the south may be found by fixing a stick vertically in the ground and measuring the lengths of the shadows cast by the stick. How does this help? Draw a figure.

5. Find the south by the scout's method. Hold a watch horizontally with the hour hand pointing to the sun. Bisect the angle between the hour hand and 12 o'clock. The bisector points to the south. Can you explain why this is so?

6. Can you tell the time approximately by looking at the sun? How would you proceed to tell the time by means of the sun and a weather-vane?

7. Suppose you have to find the south when summer-time is in operation. What correction would you make?

8. Find the Great Bear. Make a drawing and put in as many stars as you think belong to this constellation. Mark the brightest by figure 1 and the others by figures 2, 3, etc., according to their brightness.

9. Point out the Great Bear, the Pole Star, Cassiopeia, and Orion. Make a drawing showing their relative positions, and state the time of day and the date of your observation.

10. Try to find some reddish and bluish stars.

11. What are the points of the compass between the north and the east? Draw two lines at right angles to each other and at the ends put N., S., E., W. Show the N.E., S.S.E., and N.W. by N.

12. Name winter and summer birds which are visitors to the British Isles. Where do they come from? How have they found their way here? Why have they come?

13. The turkey is a native of America. Why was it not found in the British Isles before the discovery of America? What American birds visit us (*a*) in summer, (*b*) in winter?

CHAPTER IV

MEASUREMENTS

In olden times people must have been seriously handicapped in trading with each other without such exact measurements as the foot-rule or yardstick. If anyone wanted to measure the width of a table or board he would open his hand as wide as possible and see how many 'spans' wide it was (Fig. 19).

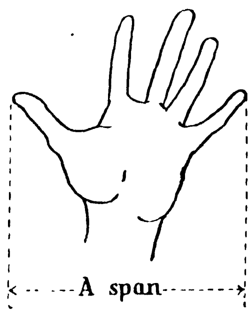


Fig. 19

Sometimes instead of the span the 'hand' was used, by folding the thumb out of the way (Fig. 20). The heights of horses are still given in hands, which, originally differing in size according to the person measuring, is nowadays taken as four inches in length. The 'foot' was also

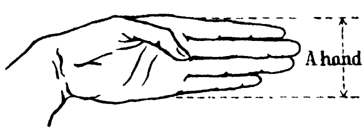


Fig. 20

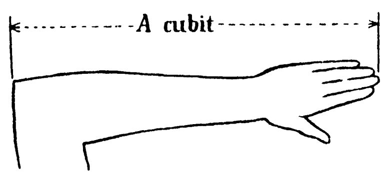


Fig. 21

used in measuring lengths and breadths; and the 'step' of a full-grown man is nearly a yard in length. In measuring cloth a salesman sometimes used the 'cubit'—*i.e.*, the distance between the elbow and the finger-tips (Fig. 21)—which varied in different

countries from 18 to 24 in. The 'yard,' measured from the middle of the chest to the end of the outstretched arm (Fig. 22), was another commonly used measure.

Sometimes a man would sell to a purchaser as much land as he could walk round between sunrise and sunset, and it would be to the advantage of the latter to hurry as fast as he could. In the Bible we read of some of these old measures. For example, Noah's Ark was 300 cubits long, 50 cubits wide, and 30 cubits high. Goliath was six cubits and a span in height.

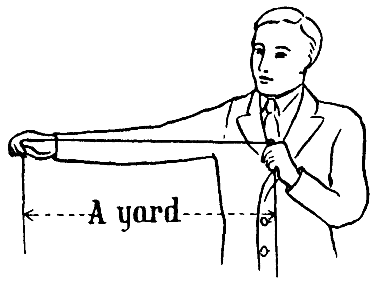


FIG. 22

Such measures were bound to vary in length according to the person doing the measuring. One man can span 2 in. more than another, a big percentage difference. At one time the English 'foot' averaged 13·22 in. in length, and the old English mile was one of ten and not eight furlongs.[1] In Saxon times the standard measures were kept at Winchester, and copies were legally compared with them and stamped. Later the standards were removed to Westminster. Gradually the foot became universally one of 12 in. and the yard equal to 3 ft. or 36 in. The last measure of length is the distance between two marks on a metal rod, kept in London. By reading about old buildings and comparing their reputed measurements with our measurements to-day we can find out how, say, the foot has varied throughout the ages.

[1] See note at the end of this chapter.

It is important that you should be able to measure lengths, heights, areas, etc., rapidly and accurately.

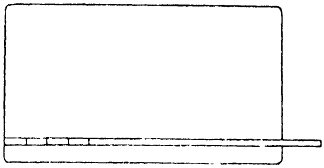


FIG. 23

Let Fig. 23 represent the top of a table whose length and breadth you wish to know. Either measure along the edge of the table, or, if the corners are rounded, do as shown in the sketch, keeping the ruler the same distance from the edge all along its length.

When you are measuring a person's height let the book or ruler which touches the top of his head be quite horizontal; not as in the sketch (Fig. 24). When he has moved away from the wall the tape-measure must be vertical, or his height will appear too big (Fig. 25).

FIG. 24

Rulers, tape-measures, yardsticks, etc., are for measuring straight lines; other devices have been invented to get the real length of a curve. Suppose you have to find the length of the curved line shown in Fig. 26.

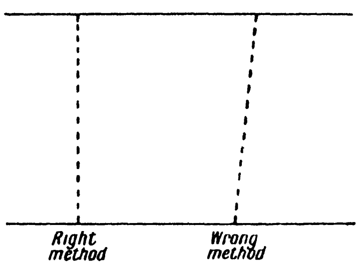


FIG. 25

(*a*) You may take a piece of string and place one end at A. Carefully place the string over the curve until you arrive at B. Pinch the string at B, stretch it along a ruler, and read off the length of the portion that covered the curved line.

(*b*) Open a pair of compasses or dividers so that the feet are $\frac{1}{4}$ in. or $\frac{1}{2}$ in. apart and, starting at A, 'step'

along the curve until you come to B. Count the number of steps and allow for the small piece over.

(*c*) Another way is to take a cork and draw a line

FIG. 26

FIG. 27

on one end of it (Fig. 27). Place the mark over one of the divisions of a ruler and roll the cork round until the mark comes to the ruler again. This will give you the length of the circumference. Now roll the cork along the line and so find the length.

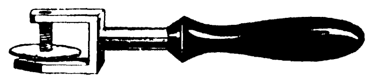


FIG. 28

(*d*) The opisometer is used in a similar way to the cork, but gives more accurate results. Run the wheel along the line to be measured, and then run it backward along a ruler (Fig. 28).

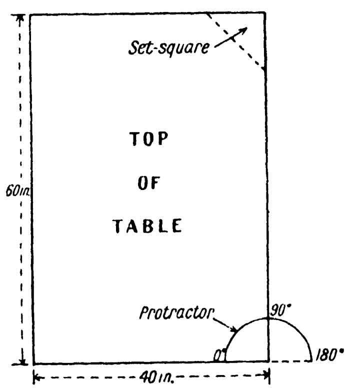


FIG. 29

Fig. 29 represents the top of a table. It is 40 in. wide and 60 in. long. The angles are all right angles. If you use a protractor you will find that each angle contains 90°, and a set-square just fits into each corner of the table.

You could divide the width into forty parts each equal to an inch; and the length into sixty equal parts, each of which is an inch long.

If you could draw lines along and across the table at these divisions you would divide it into 2400 little

squares, all of the same size. Each of the squares is an inch in length and an inch in breadth, and is called a square inch, which we write for short as 1 sq. in. The table is said to have an area of 2400 sq. in.

A piece of wood 10 in. long and 9 in. broad contains 90 sq. in. Another piece $1\frac{1}{2}$ ft. long and 9 in. broad contains 18 in. × 9 in., or 162 sq. in.

The top of a table, sides of a brick, etc., are all of the shape to which the name 'rectangle' is given. The area of a rectangle is obtained by changing both the length and breadth to inches, or feet, etc., and multiplying the two numbers together. If the answer is a large number of square inches they may be brought to square feet. There are 144 sq. in. in 1 sq. ft. You can prove this by drawing a square whose sides are each 1 ft. and drawing lines across at intervals of 1 in. There are 144 small squares, each one inch square.

To find the volume of any solid shaped like a brick multiply together the length, breadth, and thickness (or height), each expressed in terms of the same measure of length.

EXERCISES

1. Find the length of your 'span,' 'hand,' 'foot,' 'cubit,' and 'yard.' Write down in tabular form the corresponding lengths for different scholars in your class.

2. Measure your partner's height.

3. Find his chest measurement before and after he has filled his lungs and so find his chest expansion.

4. Measure the length of his leg, up to the knee and from there to the top of his leg.

5. Compare the distance from finger-tip to finger-tip when his arms are stretched out at his sides with his height.

6. A Boy Scout measures the width of a river as follows:

He finds two points (A and B) facing each other on opposite banks of the river (Fig. 30).

He then walks along one bank towards, say, C until the line CB makes an angle of 45° with the bank AC—he could use a 45° set-square to enable him to get the angle. ABC is an isosceles triangle, AB and AC being equal in length. So he measures AC and then knows the length of AB. If you have no river find in this way the width of a street.

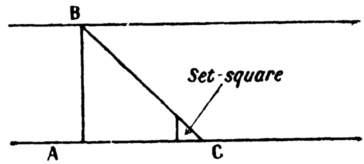


FIG. 30

7. Tommy Smith was often late for school, so his teacher made him tell which way he came to school. He said, "I come along London Road to Chester Street,

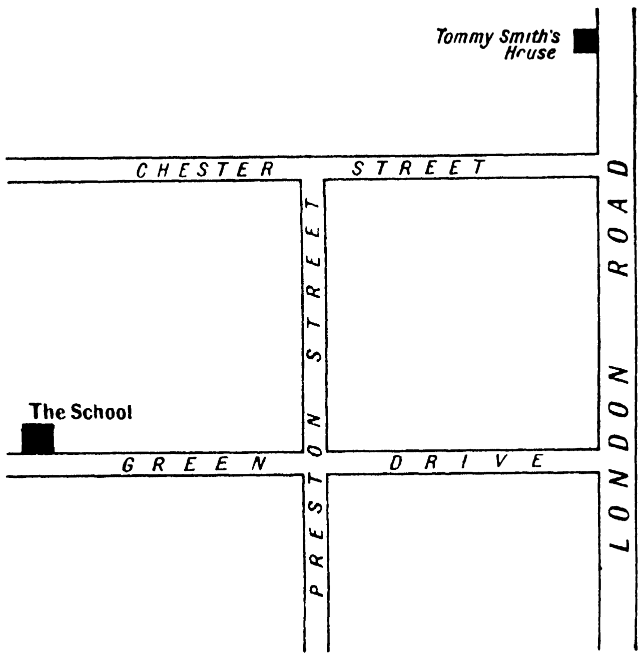


FIG. 32

and then along Chester Street to Preston Street, and then along Preston Street to the Green Drive, and so to school."

Is there a shorter route for Tommy?

8. Find the length, breadth, and thickness of this book.

9. Find the area of a carpet 6 ft. long and $3\frac{1}{2}$ ft. broad.

10. What is the area of a piece of glass 19 in. long and 11 in. wide?

11. Find the area of the door in square inches and in square feet.

12. AB is a wide street, and to avoid motor accidents pedestrians are advised to "Cross Here" (Fig. 31).

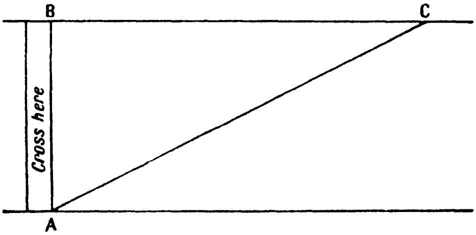


FIG. 31

Suppose a person takes no notice of this advice, and instead of crossing at AB he crosses at AC. Count the number of millimetres in each line and, assuming that he can cross at AB in five seconds, work out how long it will take him to cross at AC.

13. Find the area of one of the window panes.

14. Find the volume of a brick.

15. What is the total volume of water in a tank whose measurements are 2 ft., $1\frac{1}{2}$ ft., and 1 ft.?

16. What is the total volume of air in your classroom? How much does it average per pupil?

17. The road from A to B consists of five lengths each 100 yds. in length (Fig. 33). How much shorter is the distance 'as the crow flies'?

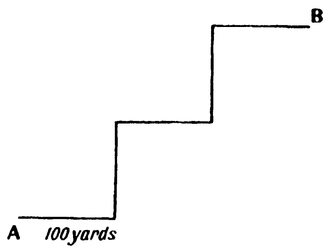


FIG. 33

Note. Readers should always be on the alert when they come across references to units used in other days, especially when they endow people with almost superhuman records. *E.g.*, in *Fruit and its Cultivation*, by T. W. Sanders, there is a reference to Phillips' *History of Cultivated Fruits*, in which it is stated that raspberries were much cultivated early in the last century in the neighbourhood of Isleworth and Brentford for supplying to distillers for making raspberry brandy and raspberry vinegar. "Raspberries which are intended for the table are brought by women on their heads; their load consists of a round or basket, containing twelve gallons, of three pints to a gallon; and, although the distance is ten miles from Isleworth to Covent Garden Market, they regularly perform the journey in two hours. . . . These female porters . . . in their long journeys seldom walk at less a pace than five miles per hour."

A Cheshire acre, which is greater than two statute acres, is occasionally used, as are other 'acres' in some other English counties, Ireland, and Scotland.

CHAPTER V

MAPS AND PLANS

SOMETIMES a drawing has to be reproduced faithfully in every respect. To copy a circle whose radius is 1 in. you have only to draw another circle 1 in. in radius. To reproduce a square each side of which is 1 in. in length you draw a horizontal straight line and mark

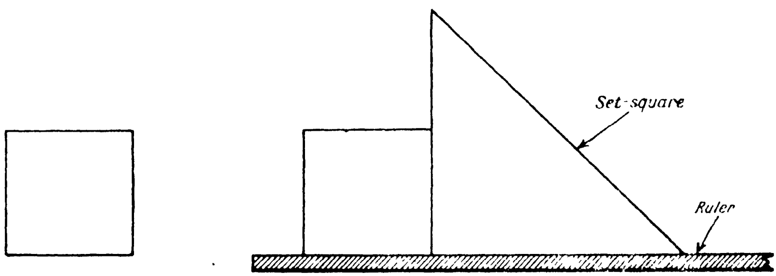


FIG. 34

off 1 in. Then with the aid of a ruler and a set-square draw two vertical lines one at each end of the line. Mark a point on each of these lines 1 in. from the horizontal line and join the two points by a straight line. A square like the first is obtained (Fig. 34).

Sometimes we have to make large drawings of small objects, like enlarging a photograph. It is important that every part be enlarged in the same proportion. If the length of a man's foot in a small drawing is one-sixth of his height it must be one-sixth of his height in an enlarged one. Fig. 35 shows a square with $\frac{1}{2}$-in. sides. Make an enlarged drawing in which each side shall be 1 in.

Take a line AB, 1 in. in length, and complete the square in the way shown.

Suppose you have to enlarge Fig. 36 (i), which shows a quarter of a square cut away. The shaded portion

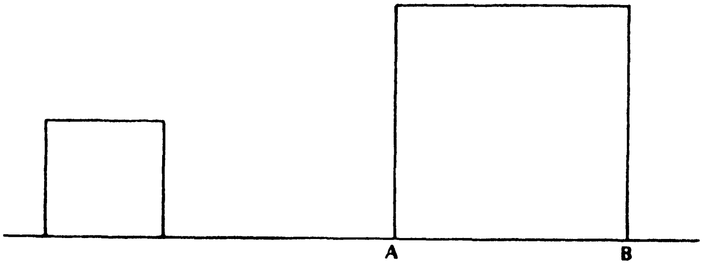


FIG. 35

shows where the original square was. Now make an enlarged drawing of the original square, dividing it into four equal squares by dotted lines, as shown in Fig. 36 (ii). Outline in ink the portion made up of the squares marked 1, 2, and 3.

Generally we have to reduce the size of drawings. Maps, town-plans, etc., are simply small drawings of

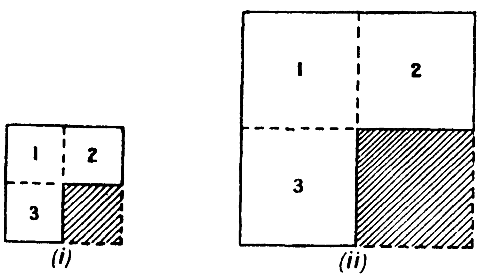


FIG. 36

big countries, towns, etc. Great Britain and Ireland have together an area of 121,000 sq. miles, but maps of them smaller than this page are often required, and the map must look like the original, every part being proportionately reduced in size. Before we make such

a drawing we have to decide what is known as the scale. For example, from John o' Groats to Land's End is actually 620 miles. This page is about 7 in. in length, so that to include a map of the British Isles on this page every 100 miles would have to be reduced to 1 in. The scale would be 100 miles to the inch. We could take a scale of 100 miles to each half-inch, but if we did so the map would occupy less than a quarter of this page and we should not be able to read the names as easily as in a larger map. You will have many opportunities of drawing maps, so we will turn to a special kind of map called a plan. Before doing so, however, it will be as well to point out that whenever an enlarged or a reduced drawing is made, whenever a map or a plan is drawn, the new drawing is always similar in every respect to the original. This will be seen by examining Fig. 37, which shows two triangles fitted one inside the other. If you measure the angles of triangle ABC you will find that they are equal to those in triangle AB′C′. If we regard AB′C′ as the enlarged figure, where AB′ has been made double the length of AB, then it will be found that AC′ is double the length of AC and B′C′ double the length of BC. Or we might regard the original as AB′C′ and ABC as the reduced figure.

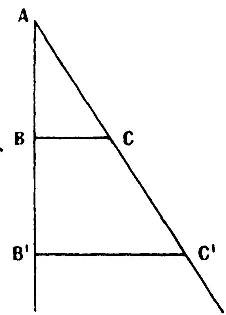


FIG. 37

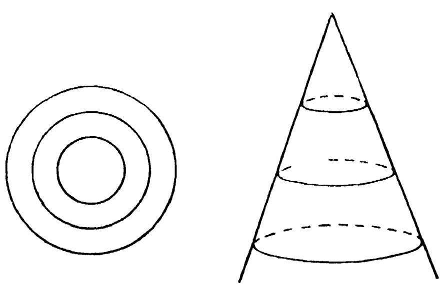


FIG. 38

Figs. 38 and 39 each show a group of similar circles and squares respectively. (Can you have dissimilar circles and squares?) The circles are of different sizes, but you will see that they all fit within the same framework. The same is true of the squares.

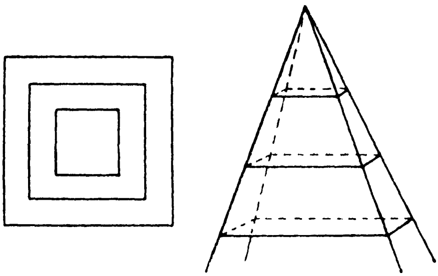


FIG. 39

If you were to ask a builder what he was building you would be surprised if he answered, "I don't know yet." No builder begins to build until he does know. Not only must he know what he wants to build, but he must get permission from the Local Authority before he starts. Drawings, or plans, are prepared, and they are carefully examined, and if they are considered satisfactory and in accordance with the regulations in force in that area he is allowed to proceed. His work is inspected from time to time to see that he is building in accordance with his own plans. It is very useful to be able to draw plans, for a person who can draw plans will soon be able to read the plans of other people, and

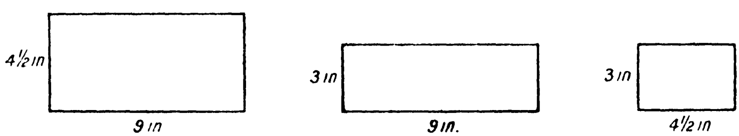


FIG. 40

by inspecting a plan he will also be able to tell what a building will be like without actually seeing it.

First draw a picture of what you would see if you looked down on a brick on the floor. You would see

an oblong, or rectangle, the shape of which would depend on the way the brick was resting on the ground. The three possible shapes are shown in Fig. 40.

These are three different plans of the brick. If

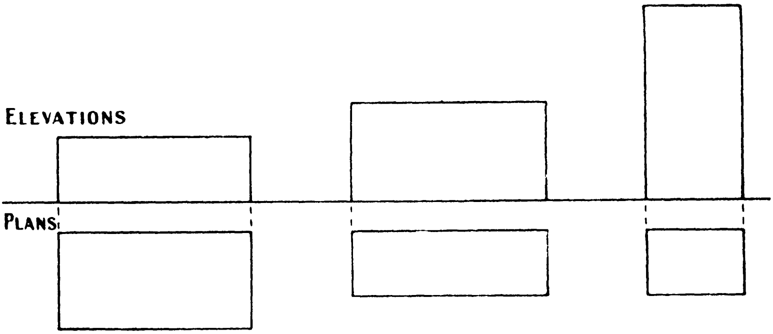


FIG. 41

instead of a picture from above you made a picture from the side you would get, not a plan, but an elevation. The elevations and plans together would look like the drawings in Fig. 41.

Suppose you had to draw a plan of the school-room or laboratory. You would first measure its length and breadth. Suppose it is 7 yds. long and 6 yds. broad. To reproduce this large room you would have to use a scale. say 1 yd. = $\frac{1}{4}$ in.

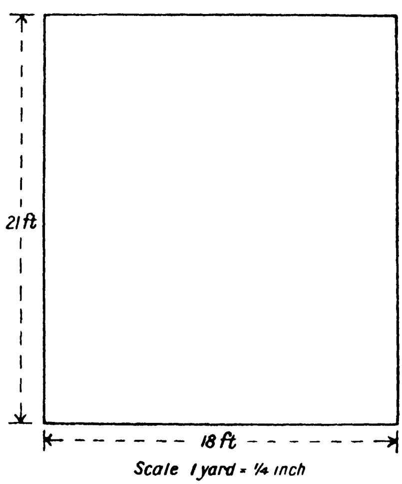


FIG. 42

The rectangle will be $1\frac{3}{4}$ in. long and $1\frac{1}{2}$ in. wide. This is a plan of your room (Fig. 42). You can, if you

wish, show the plan of the teacher's table, the front row of the pupils' desks, and the position of the door and window (Fig. 43).

There are two or three things that you may not have noticed:

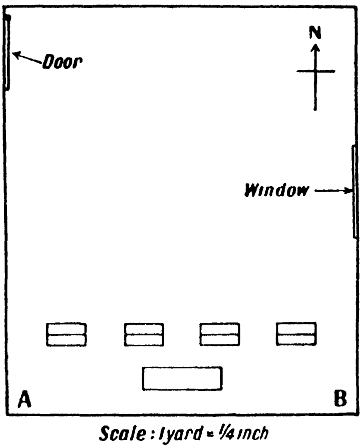


FIG. 43

(1) Probably from the window you can see the sun during a part of the day. Classrooms are generally on the sunny side of the school, for sunlight is absolutely necessary for good health. (Which is the sunny side of a school?) No plan is complete which does not show the position of the sun.

(2) The desks are arranged so that the window is on your left hand. When you are writing you should always have the light coming to you from the left, so that your writing is not in the shadow. When you are reading the light may come from either the right side or the left, so long as it is not in your face. These precautions should be taken so that your eyes will not be injured.

(3) In what corner of the room is the blackboard, A or B? Why is one corner a better place than the other? Why does the teacher place a movable blackboard at one side and not in the front of the class?

The elevation of your classroom should be drawn. A wall with neither window nor door will be just a rectangle. A wall with a window in it will look like

Fig. 44. Fig. 45 shows the elevation of a wall with a door in it.

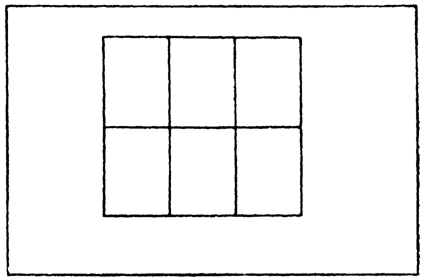


FIG. 44

Remember that the sun rises in the east and sets in the west. In the above classroom the sun is seen in the early morning, in the middle of the day it is hidden by the school, and later in the day, when it is sinking in the west, it cannot be seen in the classroom except when the door is open—refer to Fig. 43.

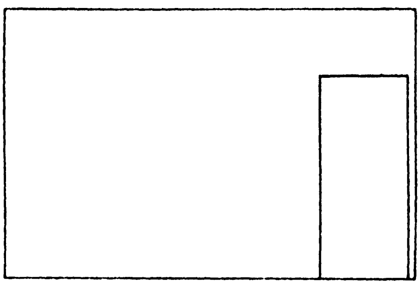


FIG. 45

A plan of the whole school might show a main corridor and a number of classrooms branching off from it, or a quadrangle with the school buildings arranged round it. The plan of such a school might be as shown in Fig. 46.

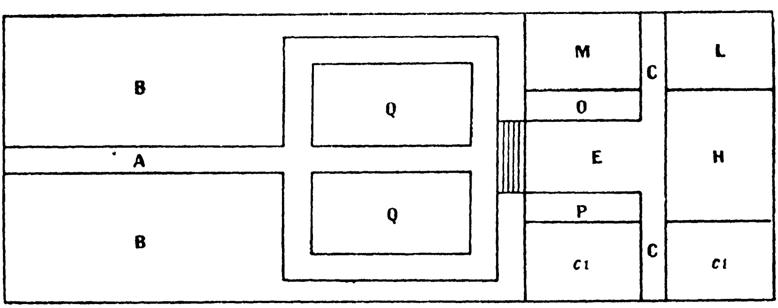


FIG. 46

A, is the school drive; B, the playing-fields; C, the corridor; Cl, the classrooms; H, the hall; M, the masters' room; P, the prefects' room; L, the library; Q, the quadrangle; E, the entrance hall; O, the office.

A plan of a village might show the main street with houses, shops, a church or chapel, etc., arranged on one or both sides of the street (Fig. 47). If you consult a motoring guide you will see scores of these plans, showing the street, principal buildings, works, etc.

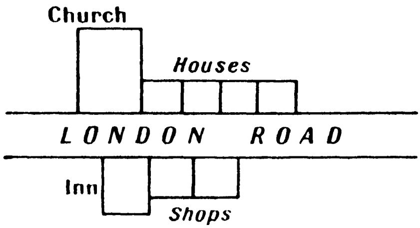


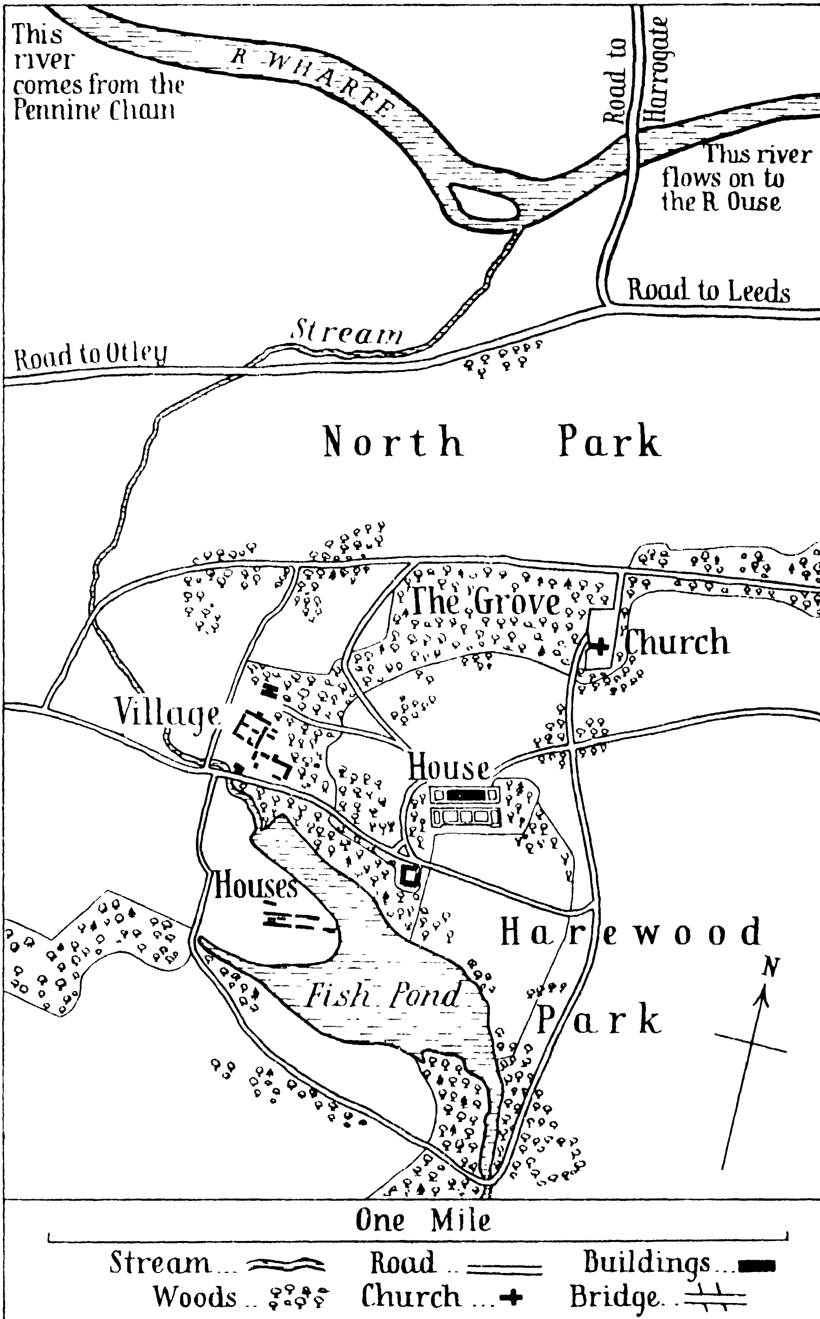
FIG. 47

Lastly, aerial maps have become very fashionable. Aeroplanes have even been used to discover lost cities, for it is found that any unevenness in the ground due to walls, etc., being covered up comes out well in the photograph (Fig. 48).

Fig. 49 and Fig. 50 show an aerial photograph and a map respectively of Harewood House and its surroundings.

EXERCISES

1. Draw a plan and an elevation of a ball 2 in. in diameter.
2. A brick 9 in. long, $4\frac{1}{2}$ in. broad, and 3 in. thick is placed on its end. Draw two plans and two corresponding elevations of the brick.
3. Make a drawing of your garden showing the footpaths, the different beds, the orchard, etc.
4. Draw a plan of your house and garden so as to show the main features of interest. Then suppose it is for sale. Prepare an advertisement which would make a potential purchaser think that it is a very desirable residence.
5. Draw a plan of your classroom showing the position of the desks, blackboard, windows, door, etc.
6. Draw the main corridor of your school, showing the arrangement of the classrooms, etc., connected with it.
7. Draw a plan of your village or of the district immediately round your school.
8. Make a survey of part of your local district. Show streets, buildings, fields, crops, etc.



This river comes from the Pennine Chain
R. WHARFE
Road to Harrogate
This river flows on to the R. Ouse
Road to Leeds
Stream
Road to Otley
North Park
The Grove
Church
Village
House
Houses
Harewood
Fish Pond
Park
N
One Mile
Stream
Road
Buildings
Woods
Church
Bridge

FIG. 50

9. Suppose that each of two rooms, A and B, facing as in Fig. 51, has two windows in adjacent sides. Which room do you think will have more sunshine, A or B? Each W indicates a window. Is the sun visible all day from any window?

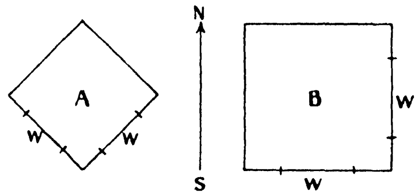


FIG. 51

10. Which room at home gets (*a*) early morning sun, (*b*) afternoon sun, (*c*) no sun at all?

11. Place a dot in the centre of a page to represent your home town. Show the N. and S. line. Place dots to represent near-by towns, and by means of a scale make the distances as correct as possible.

CHAPTER VI

FALLING BODIES: THE LAWS OF MOTION

HAVE you noticed how a ball behaves when a cricketer throws it in? However hard he throws the ball, its path is something like the curve shown in Fig. 52.

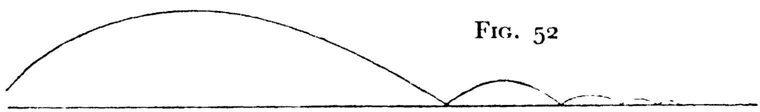


FIG. 52

It may be thrown very high into the air, but it soon comes down. Do you know why this is so? The fact itself was known to, and made use of by, the earliest inhabitants of the globe. They knew that if they were creeping along the branch of a tree and the branch snapped they would quickly come to earth, if not to grief. (Fig. 53.)

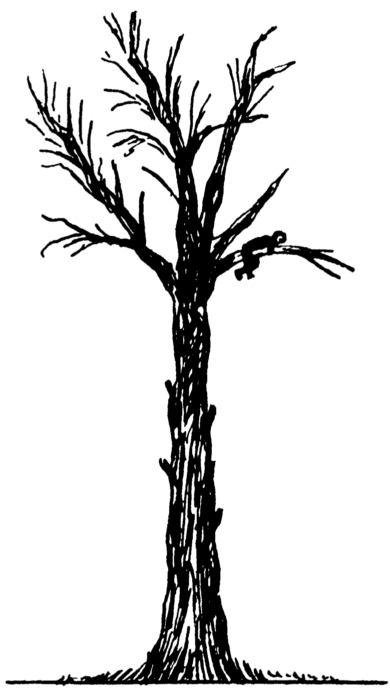


FIG. 53

When they were hungry, and were unsuccessful in the chase, they used to dig a big pit, put a number of pointed stakes upright at the bottom, and then skilfully cover the hole with

branches and leaves. The unwary hippopotamus or mammoth, passing over the spot on its way to the drinking-pool, fell through the flimsy covering, and was wounded and killed (Fig. 54).

People living in cold climates found out that when they got on an icy incline a gentle push at the start would carry them to the bottom, and they would only come to rest when the slide reached the horizontal.

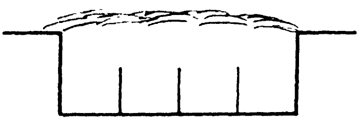


FIG. 54

Monkeys, too, make use of this pulling-down force when they drop their coconuts from the tops of the palm-trees; so do birds when they drop shellfish from their beaks on to stones so as to get at the dainty morsels within.

This force which pulls things down to the earth is now called the 'force of gravity,' and we shall learn later in this chapter that it was Sir Isaac Newton, who lived in the seventeenth and eighteenth centuries, who first showed that it not only caused bodies to fall to the ground but held the universe together. In the year that Newton was born Galileo, another great scientist, died. Every boy and girl should know something about the work of these two great scientists.

GALILEO

Galileo (1564–1642) was born at Pisa. His father was a nobleman of good education, and although poor he made sacrifices to send his son to the University of Pisa to study medicine. Galileo soon gave up the study of medicine for physics and mathematics, and early began to make discoveries. During a church service

he noticed a lamp swinging from the roof. As he had no watch he 'timed' the swings by means of the pulse (see Chapter VII), which beats fairly regularly at a rate of about 72 per minute.

In 1590, when he was only twenty-six years of age, he was appointed Professor of Mathematics at Pisa. Being rather outspoken, he got into trouble, and was glad to move to Padua. Here he constructed a telescope, and by means of it he discovered some of the moons of Jupiter and the rings of Saturn. Unfortunately his discoveries and inventions got him into further trouble that he could not have anticipated. By means of his telescope he had discovered sunspots on the sun and craters on the moon. He was naturally delighted, and asked others to look at these wonderful sights. The philosophers and so-called men of science were very angry with him, and refused to look through his telescope. Why? Because he had pretended to detect blemishes on the beautiful faces of the sun and the moon.

> As in the case of the spots on the sun, Galileo's announcement of this discovery (Jupiter's Moons) was received with incredulity by those philosophers of the day who believed that everything in nature was described in the writings of Aristotle. One eminent astronomer, Clavius, said that to see the satellites one must have a telescope which would produce them; but he changed his mind as soon as he saw them himself. Another philosopher, more prudent, refused to put his eye to the telescope lest he should see them and be convinced. He died shortly afterwards. "I hope," said the caustic Galileo, "that he saw them while on his way to heaven." [1]

His continued advocacy of Copernicus's great

[1] *Astronomy for Everybody*, by Professor Newcomb (Pitman).

discovery that in our solar system the sun is the central body and the planets, including the earth, revolve round it brought him into violent conflict with the Church. He was condemned by the Inquisition, his books were publicly burned, and he was imprisoned for a time. Milton visited him, and in *Paradise Lost* refers to him as the "Tuscan Artist"—

> . . . the Moon, whose Orb
> Through Optic Glass the *Tuscan* Artist views
> At Ev'ning from the top of *Fesole*,
> Or in *Valdarno*, to descry new Lands,
> Rivers or Mountains in her spotty Globe.
>
> *Paradise Lost*, Book I

He was liberated after making a long and humiliating declaration, confessing his error and sin in having accepted and advocated the Copernican theory of the earth's motion round the sun.

> "I abjure, curse, and detest the said errors and heresies . . . and I swear that I will nevermore in future say or assert anything verbally or in writing which may give rise to a similar suspicion of me; but that if I shall know any heretic or anyone suspected of heresy, I will denounce him to the Holy Office or to the Inquisitor and Ordinary of the place in which I may be."
>
> It was a tragic spectacle, rendered more tragic by this recantation of the conviction of a lifetime. For many years currency was given to the story that as the old man rose from his knees after his abjuration he murmured, "It moves, nevertheless." The story has long since been discredited, but doubtless it is a correct enough interpretation of what was going on in his mind. If he did not speak the words, he thought them.[1]

It is with his experiments on falling bodies that this

[1] Article on "The Tercentenary of Galileo's Final Appearance before the Inquisition" in the *Manchester Guardian*, June 9, 1933.

chapter is mainly concerned, and, innocent-looking as this work may seem to us, it succeeded in ranging great opposition against him. Nearly two thousand years before there lived in Greece a famous philosopher named Aristotle. The Greeks were very interested in most questions, and they tried to explain why things happened and how they worked; but unfortunately they thought that they could reason everything out. Many things can be reasoned out, but in other cases experiments are necessary. We know that the Greeks reached wrong conclusions in many instances, but so great was Aristotle's authority that few ever thought of questioning what he had said. For example, he reasoned out and taught the world (and set the world wrong for hundreds of years) that the heavier the body the faster it fell to the ground; if pieces of iron and wood of the same size were dropped from the same height at the same time the iron would reach the ground first. Galileo did not believe this. He determined to carry out an experiment to prove that he was right and Aristotle was wrong. He went to the top of the Leaning Tower of Pisa and dropped different objects from a window to the foot of the Tower. He found, as he expected, that all bodies fall at the same rate, although the air made a difference when light bodies such as paper and feathers were used. If the air could be got rid of falling bodies would all behave alike. This can be proved by experiment, but the experiment is not an easy one for you to carry out. In the 'guinea and feather' experiment a guinea and a feather were placed in a long tube out of which the air had been drawn by means of an air-pump. The tube was then quickly turned upside-down, when it was seen that the

two objects did fall at the same rate. As an alternative experiment, take a coin and on the top of it place a circular piece of paper. Drop them together. The coin keeps the air from the underside of the paper and they arrive at the ground together.

Having proved that all bodies, whatever their weight and size and shape, fall to the earth at the same rate,

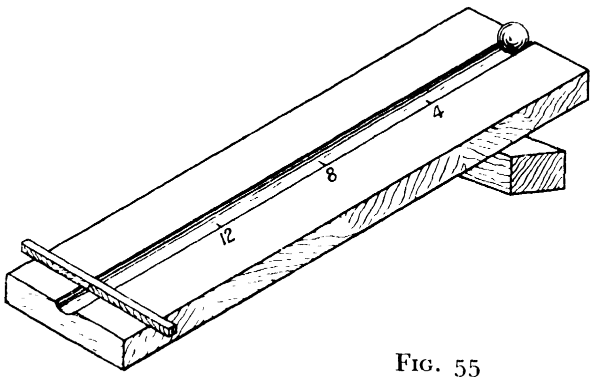


FIG. 55

Galileo next tried to find what the rate of fall was. He could have erected a series of ladders against some tall building and from different rungs dropped a pebble, but he had neither watch nor clock. We now know that in the first second a body falls 16 ft., and in two seconds 64 ft., so that in the second second it falls 48 ft. To make this great discovery Galileo rested one end of a smooth grooved plank on a block and allowed a sphere to roll along the groove (Fig. 55). He timed the sphere by using a large tank of water with a small hole in the bottom of it. This acted as a 'water-clock.'

He held the sphere at division 0, and when he released it he removed his finger from the hole in the tank. When the sphere hit a cross-piece at some

prearranged division, say 12, he quickly closed the hole in the tank. Then he weighed the water. It is clear that the water which ran out of the tank was proportional to the time during which the sphere was rolling. By these simple means Galileo discovered an important law, namely, that the space covered by the rolling ball is proportional to the square of the time. This means that if the ball rolls 5 ft. in one second it will roll 20 ft. in two seconds and 45 ft. in three seconds. Nowadays we use a stop-watch in place of Galileo's water-clock, and the results are a little more accurate.

The steeper the incline the quicker does the sphere roll in unit time, but when the incline is vertical, or when the sphere is simply dropped from a height, it falls 16 ft. in the first second. The results should be tabulated as follows:

Distance rolled by the Sphere, in Feet	Time, in Seconds	Square of the Time
1	1	1
4	2	4
16	4	16

Scientists often express their results or discoveries in graphical or 'picture' form. For example, Figs. 56 and 57 show the above results in graphical form. Squared paper is essential for this purpose.

Draw two lines, AB and AC, at right angles to each other. Let the horizontal line AC (Fig. 56) represent time in seconds, and the vertical line AB represent distance in feet. Choose your scale so that a fairly large figure is obtained. The ball starts from rest and at the end of one, two, and four seconds the distances

rolled are one, four, and sixteen feet respectively. These times and distances are shown in Fig. 56. At times one, two, and four seconds vertical lines are drawn, and at the distances one, four, and sixteen feet horizontal lines are drawn to cut the above vertical

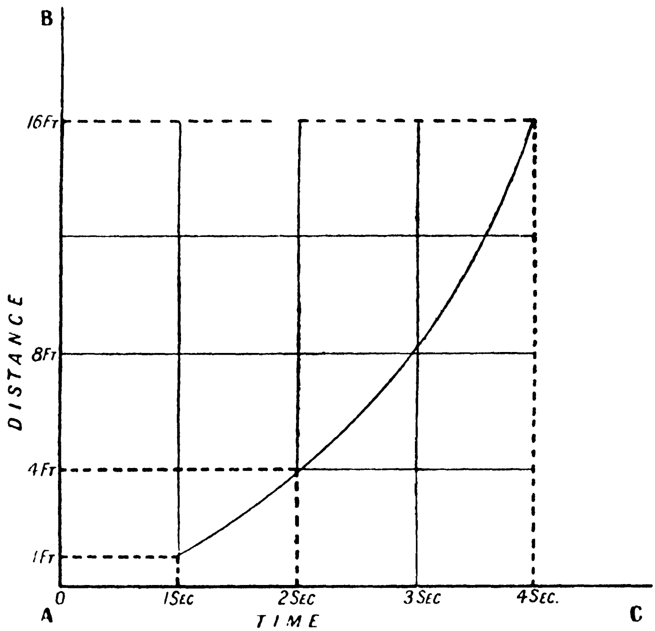


FIG. 56

lines. The time one second corresponds to the distance one foot. Where the two lines, one vertical and the other horizontal, intersect make a dot or a cross. Similarly mark the other two points of intersection. The three points do not lie on a straight line. Draw a smooth curve that will pass through each point. If the distance covered is graphed against the square of the time a straight line is obtained (Fig. 57), thus proving Galileo's law that the space covered by a rolling or

falling body is proportional to the square of the time.

Suppose we substitute for Galileo's inclined plane a tall ladder, or drop an object from the windows on the

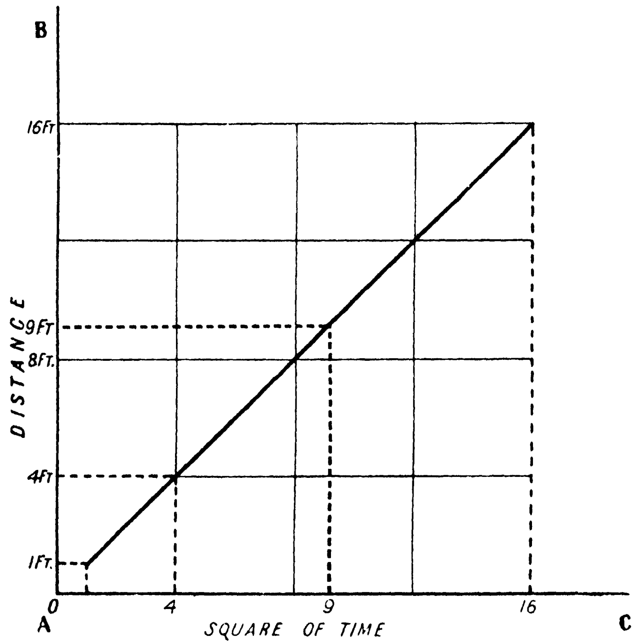


FIG. 57

first, second, third, etc., stories respectively. It is then found that the object falls

16 ft. in 1 sec.
$16 \times 2^2 = 64$ ft. in 2 sec.,
$16 \times 3^2 = 144$ ft. ,, 3 ,,
$16 \times 4^2 = 256$ ft. ,, 4 ,,

From these data we can calculate that:

In the first second it falls 16 ft.
,, second ,, ,, 48 ft., *i.e.*, $(16 + 32)$ ft.

In the third second it falls 80 ft., *i.e.*,
$(16 + 32 + 32)$ ft.
,, fourth ,, ,, 112 ft., *i.e.*,
$(16 + 32 + 32 + 32)$ ft.,
etc.

Neither does a ball, thrown up into the air, move at the same pace throughout its flight. When it leaves your hand it may be moving very fast, but at its highest point it is not moving at all—for a very short time it is 'standing still' in the air—then it begins to fall, and when it reaches the ground it has the same speed as when it started, only it is travelling in a different direction (Fig. 58).

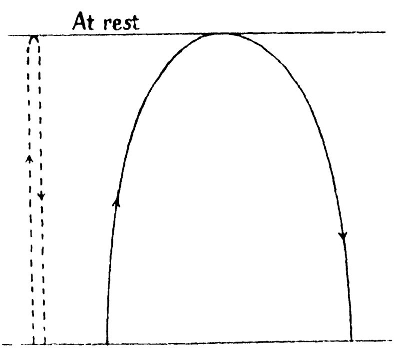


FIG. 58

You would rather be hit by a ball that had only fallen 5 ft. than by one that had fallen 50 ft., for the greater the distance of fall the greater the speed, or velocity.

It is possible to find the depth of a well or pitshaft by dropping a stone down. By means of a stop-watch find the time the stone takes to reach the bottom, say, $4\frac{1}{5}$ sec. By Galileo's law the depth is $16 \times (4\frac{1}{5})^2$ ft., *i.e.*, 280·2 ft.

In doing this experiment don't fall into the well.

The following definitions should now be learnt by heart:

Rest. A body is said to be at rest when it does not change its position with respect to other bodies.

Motion. When a body changes its position with

respect to other bodies it is said to be moving or in motion.

Velocity. Velocity is the rate at which a body changes its position. If it moves, say, 5 ft. every second its velocity is said to be uniform; but if it is moving at different rates, say 16 ft. in the first second, 48 ft. in the second second, etc., its velocity is said to be variable.

A falling body falls

16 ft. in the first second,
(16 + 32) ft. in the second second,
(16 + 32 + 32) ft. in the third second,
(16 + 32 + 32 + 32) ft. in the fourth second,
etc.

Its speed or velocity is being increased under the action of gravity by 32 ft. per second every second. This is termed the acceleration due to gravity, and it is written

32 ft. per sec. per sec. or 32 ft. per sec.^{2}

Remember Galileo's law:

$$\text{Distance fallen} = 16 \times t^2.$$

Sir Isaac Newton

Newton was born in 1642, the year in which Galileo died. He was a delicate child, and great care had to be taken of him, yet he lived to be 85—another illustration of the old saying that creaking doors last a long time. At school (Grantham Grammar School) he was not very attentive to his work, and was often described as idle. He was not really idle but more interested in

things which did not usually find a place in the school curriculum of those days, namely, clocks, windmills, etc. Later he was possessed with the idea of excelling in school-work, and soon became head of his class.

In 1660 he entered Cambridge University and again followed his bent, and so well did he use his time that while quite a young man he discovered the composition of white light, a discovery which has had such a profound influence on other fields of science. Another great discovery was his Law of Gravitation.

We saw in Chapter III that the stars appear to keep their relative positions. This is not true of planets, comets, and meteorites. Tycho Brahe, a Danish astronomer, had observed the positions of the planets over a period of thirty years. Telescopes were unknown, but star maps were made as accurately as possible. This great astronomer prepared the evidence which later scientists were able to translate into great generalizations or laws. His pupil, Kepler, tried to find the laws which kept the planets moving round the sun. In 1618, after twenty-two years' toil, he discovered that the planets travelled in elliptical orbits and not in circular ones, and that the sun was at one focus of these ellipses. This last statement can be understood by examining a circle and an ellipse. Let F be the centre of the circle. Take a piece of thin string and fasten both ends to a pin at F. Place a pencil point at the middle of this string, stretch it tightly, and by moving the pencil around the point F trace out a circle (Fig. 59). Next take two points, or foci, F

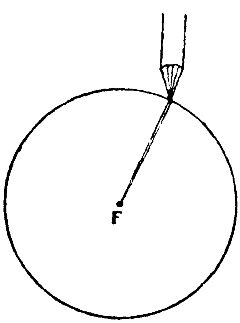


FIG. 59

and F′. Tie one end of a piece of string to F and the other end to F′. Place the pencil in position and, keeping the string as tight as possible, trace out an ellipse (Fig. 60). By altering the positions of F and F′ and the length of the string ellipses of different shapes can be drawn. Later Newton discovered the great law which explains why the planets, comets, and meteorites have such orbits. It is said that while thinking about this problem an apple fell from an overhanging branch and hit him. Most people would have rubbed the sore spot with some annoyance, but Newton, without being really pleased, asked himself, "Why did that apple fall to the ground?" "Because the earth pulled it down." "Then," continued Newton, "if the earth can pull an apple towards it one heavenly body like the sun can pull another heavenly body towards it." Instead of going straight on, the planets are pulled into elliptical orbits by the sun. Similarly the earth pulls the moon round the earth. As we shall see in a later paragraph, the moon is also able to exercise a great pull on the earth. This force, known as the force of gravitation, must be at work everywhere in the universe. A person can jump a few feet high on the earth; then he is pulled back. On the moon he could jump 20 or 30 ft. high, for the force of gravitation there is so much smaller. But on the sun the force is so strong that a person could only just drag his feet along. Later on in your scientific career you will learn that the force of attraction between two bodies depends on their masses. Also, it is greater the nearer the two bodies

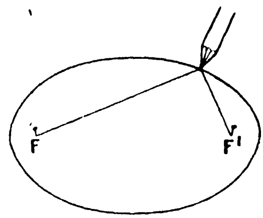


FIG. 60

are together. Newton's Law of Gravitation is expressed thus:

$$F \text{ is proportional to } \frac{M \times M'}{D^2},$$

or

$$F = \frac{G \times M \times M'}{D^2},$$

where F is the force between two bodies whose masses are M and M', D is their distance apart, and G is a constant known as the gravitation constant.

This great discovery was next thoroughly tested in many different ways and proved to be correct. The nautical almanac shows the positions of the moon and the planets, their times of rising and setting, the heights of the tides at different ports, etc., all calculated with the greatest accuracy on the assumption that Newton's Law of Gravitation is correct.

Newton was honoured in his own country as well as abroad. He was knighted in England, and made Master of the Mint. In the latter position he was responsible for maintaining the high standard of the currency, and one of his reforms was to mill gold and silver coins (except the threepenny bit), thus preventing their debasement by scraping and chipping.

He hated fuss and controversy and swank, and in spite of his greatness as a scientist he remained very humble.

> I know not what I may appear to the world, but to myself I seem to have been only like a boy playing on the seashore, and diverting myself in now and then finding a smoother pebble or prettier shell than ordinary, while the great ocean of truth lay all undiscovered before me.

Balloons

At first sight it may seem that the Law of Gravitation does not apply to a balloon which rises. Two experiments will help to show that even balloons are subject to this law.

Get a rope and let your partner take one end and pull against you. Unless you are very evenly balanced one of you will pull the other along. But the winner would not say that the loser was not trying.

Take an empty bucket and drop a stone and a cork into it. They fall to the bottom. The force of gravity pulls them down. Now put some water in the bucket and repeat the experiment. The stone sinks, but the cork floats. Is the force of gravity acting on the stone but not on the cork? It is acting on both, but the water in the bucket is, at the same time, lifting up, or buoying up, the two objects. Remember that the force of gravity is only another name for weight; that is why the stone sinks in water even though there is a force buoying it up. The cork has not much weight, and so the force buoying it up is greater than the force of gravity pulling it down. Hold the cork at the bottom of the bucket. Your force and the force of gravity are together able to overcome the uplifting force of the water. Release your hold on the cork; it rises to the top of the water again. A balloon is being pulled down to the earth, and if there were no air around it it would soon drop to the ground. The air around it determines that it shall rise, but only to a certain point.

Men have been trying to fly through the air like birds for centuries, but it was not until Cavendish in the

eighteenth century prepared hydrogen, or 'inflammable air,' the lightest gas known, that ballooning became practicable. Soap bubbles filled with hydrogen will readily rise in the air. By 1783 the brothers Montgolfier had experimented with balloons of different sizes. They used fire-balloons filled with heated air. Sometimes they ascended to great heights. The first passengers in a balloon were a sheep, a cock, and a duck. They came down safely. Then Pilâtre de Rozier offered to take a journey in one, but Louis XVI forbade it and proposed that two condemned criminals should go up in the balloon. Rozier replied, "Such honour ought not to be shown to criminals." At last the king consented to let Rozier and the Marquise d'Arlandes make a flight in a fire-balloon. A few months later hydrogen-filled balloons were introduced; and in January, 1785, Dr Jefferies (an American physician) and Blanchard (a Frenchman) crossed the English Channel. Unfortunately balloons went where the wind took them. In 1812 James Sadler attempted to cross the Irish Sea from Dublin to Liverpool, but his balloon dropped into the sea. In 1836 Green crossed the English Channel and was carried on to Germany, making a journey of 500 miles in eighteen hours. (You might read Jules Verne's *The Mysterious Island*, which tells how a party of Americans escaped from a beleagured American town during the Civil War and landed on a wonderful little island.)

Later parachute descents were made, some of the earliest with disastrous results, but in time a type of parachute was evolved that it was safe to use. In 1862 Glaisher, under the auspices of the British Association,

made an ascent, taking with him various scientific instruments. From his records we read:

> At 19,415 ft. palpitation of the heart became perceptible, the beating of the chronometer seemed very loud and my breathing became affected. At 19,435 ft. my pulse had accelerated, and it was with increasing difficulty that I could read the instruments; the palpitation of the heart was very perceptible; the hands and lips assumed a dark bluish colour, but not the face. At 21,792 ft. I experienced a feeling analogous to sea-sickness, though there was neither pitching nor rolling in the balloon, and through this illness I was unable to watch the instruments long enough to lower the temperature to get a deposit of dew.

Later in the year he was able to reach a height that he estimated to be 37,000 ft., or over 7 miles; but at this height he and his companion were in great physical distress and one was insensible.

Balloonists used to take bags of sand with them. If they wanted to rise they threw some of the sand overboard. This reduced the weight of the balloon and its contents, and it rose to a new level where its weight was equal to the weight of air displaced. (The higher you go the rarer does the air become.) If the balloonist wished to descend he opened a valve and let out some of the gas in the balloon. This reduced the volume of the balloon and consequently the air displaced was less.

Heated air, hydrogen, coal-gas (which contains much hydrogen), and hydrogen mixed with helium (used in airships) have all been used to fill balloons. Small balloons carrying instruments are now sent up, and the height, temperature, and pressure of the atmosphere are automatically recorded before the

balloon bursts, when a parachute brings the instruments gently to the ground.

During recent years journeys have been made into the stratosphere, or upper layer of the atmosphere, by Professor Piccard and various other pioneers.

Tides

Before closing this chapter we might say that the sun, which is over a million times as big as the earth, exerts

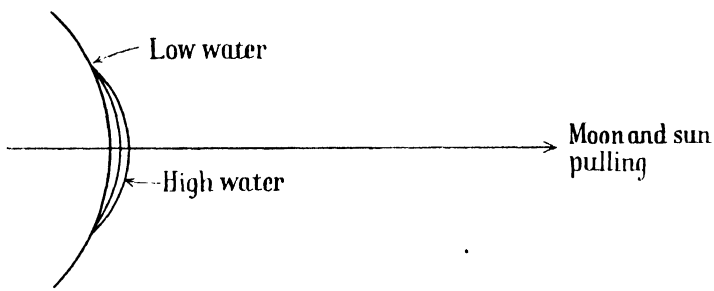


Fig. 61

a great pull on it. So does the moon, and, although it is only about one-sixty-fourth the size of the earth its pull is even greater than that of the sun, because it is so much nearer. The sun, to some extent, and the moon, to a far greater extent, cause our tides. The pulls they exert cannot alter much the shape of the solid portion of the earth, but they are able to draw the waters of the earth into heaps. Those places where the water is piled up are said to be having 'high water,' whereas it is 'low water' in the places whence the water comes (Fig. 61).

Note. The earth is able to produce tides on the sun, but they are small as the earth is so little compared with the sun.

EXERCISES

1. At 10 P.M. a boy's temperature was 100° F. After he had received suitable treatment it fell to 98° F. by seven o'clock next morning. Assuming that the temperature had fallen regularly during the interval, find by means of a graph the temperature at 3 A.M. When was his temperature 99° F.?

2. Draw a graph to show the following readings, in inches, of a barometer at 9 A.M. each day:

Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.
29·5	30	30·5	29·5	29	28·5	28

3. A man travels 9 miles due north, then 11 miles due west, and finally 15 miles due south. How far is he from his starting-point?

4. A balloon, after rising to a height of two miles, is overhead at a point six miles from its starting-point. How far is it from its starting-point?

5. Using an inclined plane or a smooth board with a groove in it, test the truth of Galileo's law of falling bodies.

6. Fill a burette with water and arrange for it to drip at a suitable rate (or let the tap drip). Take the time for 100 drops to fall. Catch the water in a beaker. Weigh the water and from the weight in grammes find the volume of water delivered. Find the volume of each drop. Place the beaker at different levels and discover if the distance that the water falls is related to the quantity of water delivered in a given time. (1 c.c. of water weighs 1 gramme.)

7. How does the angle of the inclined plane in Question 5 affect the time taken to roll down the plane?

8. Mark two points F and F′ 3 in. apart. Using these points as foci, draw several ellipses by altering the length of string. What do you notice about the ellipses? Keeping the length of string constant, alter the distance between F and F′ and again draw several ellipses. What do you notice?

9. Draw a graph to show how the heights of the tides at some port vary during the month. Indicate on the graph the different phases of the moon. What do you notice?

10. Weigh a stone in air and then in water, having the stone suspended from a stirrup of the balance by a piece of cotton. Why is there a difference in weight?

11. Weigh in water a stone and a piece of cork tied together. Subtract the weight of the stone in water. From these two

weights find the apparent weight of the cork in water. How do you account for your result?

12. A screw fell out of an aeroplane. It reached the ground in 12 sec. What was the height of the aeroplane?

13. How do we benefit from the tides?

14. Write a short life of Galileo.

15. Name two great British scientists who preceded Newton and two who immediately succeeded him. What contributions did they make to 'discovery,' or invention?

16. A projectile was shot up into the air, and continued to ascend for 10 sec. To what height did it ascend?

17. Briefly describe how the conquest of the air has been achieved.

CHAPTER VII

TIME

It is hard for us to imagine a world in which there were neither watches nor clocks. Yet for thousands of years peoples' ideas of time were very vague. They were never in a hurry. There was day-time when they were awake and, if old enough, at work; at other times they were asleep. Day-time, bed-time, sunrise, cock-crow, and sunset were words well known to all and often used. They knew that sunrise and sunset came at different times according to the season of the year. They also knew that the moon was sometimes full, sometimes only a half, sometimes a crescent, and sometimes not visible at all. The fact that the moon's phases, that is, changes from full moon to full moon again, took twenty-eight days was known to the Babylonians, as was the time of the earth's revolution round the sun, 365 days. If you read books by Fenimore Cooper or Captain Marryat's *Settlers in Canada* you will find that the Red Indians used to make appointments for the "next full moon." Little more than a hundred years ago church meetings held during the week were arranged for those nights when the full moon was visible, for few roads were lighted.

Animals tell the time in the same vague way. They wake up when it begins to grow light, feel hungry and search for food, prowl round during the day, and when it begins to grow dark they retire to rest again. Savages have advanced beyond this stage. The Red Indians

used to wander over a great tract of land searching for food, and used to describe a place as distant six wigwams away, meaning that they would have to pitch their wigwams, or tents, for the night six times before reaching their destination. Their table of 'time' would be something like this:

28 wigwams equal 1 moon.
13 moons equal 1 year.

But what of short intervals of time, such as hours and minutes?

Every single object or article or piece of machinery has been evolved, that is, invented in a very crude form and then improved. Sunrise, noon (when the sun is highest in the heavens), sunset, etc., were not enough for progressive man. People were not always ready for bed at sunset, and some unknown genius found that the discarded fat of animals would burn or even blaze when thrown into a fire. This led, after a great deal of pondering, to the invention of the tallow candle. These candles gave out light as well as heat when they were burning, and also served to reckon time. They were about the same size, and took the same time to burn. A little boy would ask his mother how long he could stay up after his supper, and she might reply, "Until the candle is burned out." Even in modern times miners who have been entombed have reckoned the time by the number of candles they have burned. King Alfred used candles with marks, or graduations, on them to tell the time (Fig. 62).

FIG. 62

Sand-glasses have been used for many centuries and are still used in very large numbers. Large ones were used in many churches during the Middle Ages (Fig. 63).

Nowadays their only use is for timing the boiling of eggs (three minutes). They are fastened to a board which can be turned round, and the sand is run from bulb to bulb.

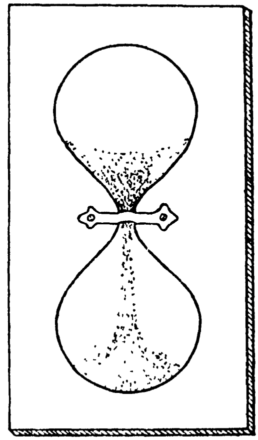


FIG. 63

Horology is the science of measuring time and the method of constructing machines for this purpose. (What is a horoscope?) The earliest of such inventions was the sundial, the first mention of which is in Isaiah xxxviii, 8 (700 B.C.), where we read, "Behold, I will bring again the shadow of the degrees, which is gone down in the sundial of Ahaz, ten degrees backward." We know nothing of the working of this sundial. The earliest type of sundial of which we have definite knowledge was one used by the Chaldean astronomer, Berossus, about 300 B.C. This type had spread to Rome before the time of Christ.

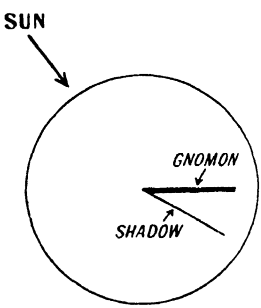


FIG. 64

The face of the dial may be horizontal or vertical. In both cases the sun must be able to shine on it. The divisions are not all equal. There is a small rod, called the gnomon, standing up from the centre of the dial. It is inclined to the face of the dial at such an angle that it is parallel to the earth's axis. The sun shines on the gnomon and this throws a shadow on to the dial (Fig. 64). The dial is graduated so that the shadow indicates the hour of the day.

It is known that about 1364 Charles V of France

summoned Henry de Vick from Germany to fit up a large clock in his palace at Paris. It was not regulated by a pendulum, for the use of pendulums for clocks was not realized until 250 years later. Then Galileo observed the lamp swinging and conceived that a swinging weight, or pendulum, might be applied to regulate clocks; but it was Huygens, a Dutchman, who perfected this idea. You can read about the later developments in clock- and watch-making in a good encyclopædia.

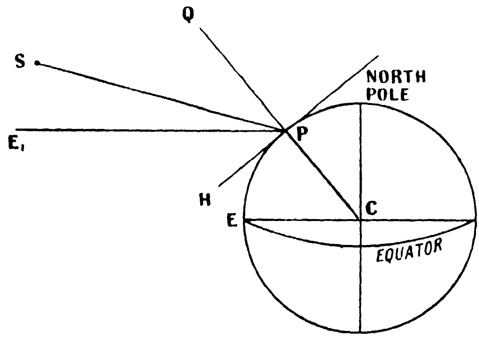


Fig. 65

One important use of a watch or chronometer is for finding the longitude of a ship at sea, a problem that was not solved until the eighteenth century. If the sun can be seen and the time of the year is known latitude can easily be calculated from the angle that the sun makes with the horizon at noon. In Fig. 65 the circle represents the earth, P the position of the observer, SP the direction of the sun's rays, E the point on the equator that is in the same longitude as P, H the horizon of the observer at P, C the centre of the earth, QP the perpendicular to HP, and E_1P a line parallel to the plane of the equator and in the plane defined by the lines SP and QP.

Note that E_1P is parallel to EC, $\angle SPH$ is the angular height of the sun above the horizon, $\angle SPE_1$ is the angular height above the equator (an angle that varies with the time of the year), and $\angle E_1PH$ is the

difference between the two angles and $\angle QPE_1$ is the latitude.

The latitude was therefore calculated by observing the position of the sun, but the angles read off by the old cross-staff and astrolabe were not very accurate. You should read about these in Sir William Bragg's *Old Trades and New Knowledge*.

In 1731 the sextant was invented, and since that time latitude has been accurately and comparatively easily obtained.

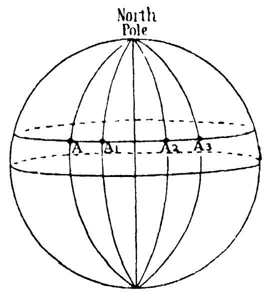


FIG. 66

On looking at Fig. 66 it will be seen that latitude alone is not very helpful to a sailor in finding his position on the surface of the globe. The horizontal circles are lines of latitude. A, A_1, A_2, and A_3 all have the same latitude, yet A and A_3 may be over 1000 miles apart. A line of longitude must also be given to define the exact position of A or A_1. All lines of longitude are circles passing through both poles. Even Columbus could not find his longitude, and that fact accounts for his being 'lost' in the Atlantic. An accurate method of finding longitude was not discovered until the eighteenth century. Anson, who sailed round the world in 1740–44, was sometimes far out in his reckoning. Sailors often sailed blindly across a sea until they 'hit' land, and then they followed the coastline until they reached the place they wanted. To find longitude a good watch or chronometer is required. Suppose it is set by the sun, that is, put right at 12 o'clock when the sun is at its highest point in the heavens. The next time that the sun is

in this position at the same place is 24 hrs. later, during which time the earth has turned completely round, that is, through four right angles, or 360 degrees.

I.e., the world turns through 360 degrees in 24 hrs.

Therefore the world turns through 1 degree in

$$\frac{24 \times 60}{360} \text{ min.} = 4 \text{ min.}$$

It sounds very easy to find longitude. Simply get a good watch and set it right by Greenwich; then note the time by the watch when the sun is highest in the heavens and compare it with your Greenwich time; if there is a difference of 2 hrs. you are one-twelfth of the distance round the world, or 30° W. or E. of Greenwich. Unfortunately, good watches were unknown in the eighteenth century, and calculations of longitude from the position of the stars and moon were difficult to carry out.

In 1714 Parliament appointed a committee to investigate the question, and Sir Isaac Newton gave evidence. He said, "One method is for a watch to keep time exactly; but by reason of the motion of a ship, the variation of heat and cold, wet and dry, and the differences of gravity in different latitudes, such a watch has not yet been made." We shall see later what he meant by the "variation of heat and cold" and "the differences of gravity in different latitudes."

Parliament offered a big prize to anyone who could devise an accurate method of finding longitude. If a watch was to be used the reward was dependent on how accurately it kept time. To get the first prize of

£20,000 it had to keep time to 2 min. in six weeks (the time taken for a voyage to the West Indies).

The prize of £20,000 was won by John Harrison, the son of a Yorkshire carpenter, who designed a balance-spring which automatically compensated itself for changes in temperature (see Chapter XI). The Government was not very ready to pay him the whole of the prize, and it was not until George III had personally intervened on his behalf that he got the £20,000.

To-day we can read the time of noon at Greenwich, construct watches which hardly vary, broadcast Greenwich time to all parts of the world, and find the longitude very accurately and quickly.

The Pendulum

It is now time to refer again to one of the earliest of Galileo's observations, that of the swinging lamp-pendulum in the church at Pisa. We have already noted that by timing the swings by the beats of his pulse he discovered the regularity of the movement. This discovery illustrates what happens very often. People may fail to find what they are looking for, but if they keep their eyes and their ears open they may discover something nearly as important as, or even more important than, the object of their quest. To repeat Galileo's experiments on pendulums a piece of string with a weight (preferably a spherical ball) at the end of it is required. Fasten the free end of the string to a beam and let the weighted string, which we shall now call a simple pendulum, come to rest. In this state any weighted string is exactly vertical.

Builders use this fact to tell when their walls are quite

upright (Fig. 67). Usually the weight they use is made of lead, and because the Latin word for lead is *plumbum* this device was called a 'plumb-line' and a worker in lead became known as a 'plumber.'

EXPERIMENT 1. To discover if the time of one swing

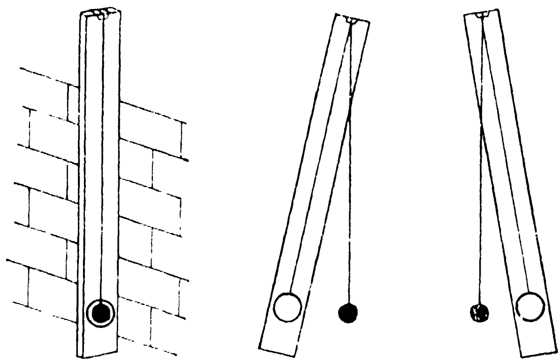


FIG. 67

is the average time of thirty swings. Fit up a pendulum having the thread or string about one yard in length and the bob about $\frac{1}{2}$ in. in diameter. Securely clamp the free end of the string between two pieces of wood or cork so that the point of suspension does not change and the length of the pendulum is constant. A burette-stand whose jaws close tightly may be used (Fig. 68). Start the pendulum swinging through an arc of about 25 to 30 degrees. This angle is called the amplitude of the swing. By means of a stop-watch find the time of a swing to and fro. Then take the time for thirty swings and find the average time for one swing. Does your discovery indicate the procedure you should adopt in carrying out pendulum experiments?

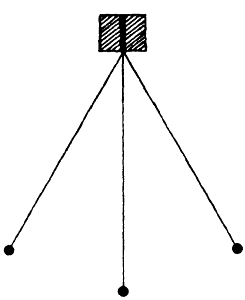


FIG. 68

EXPERIMENT 2. To discover if the time of a swing is dependent on the amplitude of the swing. If one pendulum only is available timing is necessary, but if two pendulums, exactly alike, can be fitted up, partners can take charge of one each. Pull the pendulums from the position of rest, one 10° out and the other 20° out. At the word 'Go' release both. It will be easy to see if one is gaining on the other (Fig. 69).

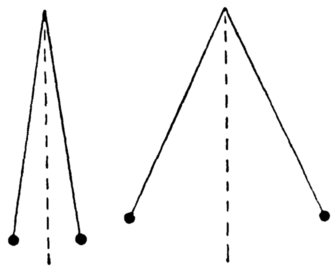


FIG. 69

EXPERIMENT 3. To discover if the time of a swing is dependent on the length of the pendulum. Find the average time of a swing when the length of the pendulum is (*a*) $4\frac{1}{2}$ ft., (*b*) 3 ft., (*c*) $1\frac{1}{2}$ ft. The length of the pendulum is measured from the point of suspension to the centre of the bob. Graph the length of the pendulum against the time of a swing, and then against the square of the time.

EXPERIMENT 4. To discover if the time of a swing is dependent on the weight of the bob. Keep the length of the pendulum the same but use (*a*) a lead bob weighing 50 grm. and (*b*) a lead bob weighing 100 grm.

EXPERIMENT 5. To discover if the time of a swing is dependent on the material of which the bob is made. Use lead and iron bobs of the same weight with strings of equal length.

Now answer the following questions:

(1) What is the time of swing (*a*) when the bob is made of lead, (*b*) when it is made of iron?

(2) Is the time increased or decreased when the

string is lengthened? Does the graph tell you anything else?

(3) Do your observations lead you to believe that the time of swing is independent of or dependent on the amplitude of the swing?

Now reason out how you would regulate the pendulum, shown in Fig. 70, of a clock that is going too fast. At the end of this pendulum there is a screw by means of which the bob can be raised or lowered.

FIG. 70

A law has been discovered relating to the simple pendulum which is expressed by the equation

$$t = 2\pi\sqrt{\frac{l}{g}},$$

where t is the time of a swing, l is the length of the pendulum, π is the symbol for a constant which has a value of about $\frac{22}{7}$, and g is the constant of gravitation, the value of which is 32 ft. per sec.^{2} when l is measured in feet, and 981 cm. per sec.^{2} when l is measured in centimetres.

If you square both sides of this equation you get

$$t^2 = 4\pi^2\frac{l}{g},$$

or

$$\frac{4\pi^2}{g} = \frac{t^2}{l}.$$

Since g at any one place and π are always constant in value, it necessarily follows that the value of $\frac{t^2}{l}$ is constant. Does this conclusion agree with the conclusion you came to when you made your graph?

EXERCISES

1. Take a candle and mark a length in inches. See if the times taken to burn separate inches of the candle are the same.

2. Fit up a glass tower with a rubber stopper in the hole at the side. Insert a tube with a narrow bore. Paste a paper scale on one side of the tower and compare the times taken to lower the level of the water by separate inches.

3. Examine and test a sand-glass.

4. Using a plumb-line, determine if various fixtures in the laboratory are vertical.

5. Find the length of a seconds pendulum, that is, one which takes 1 sec. for a complete swing.[1]

6. Sir Frank Dyson, late Astronomer-Royal, reported that Big Ben usually gained or lost only 1 sec. a day. He said, "A tray is fixed about half-way down the pendulum, and when the clock is losing slightly a half-penny or a penny is placed on the tray. This makes the pendulum vibrate slightly more quickly and gradually brings the clock to time. If the clock is gaining, a half-penny or a penny is removed."

Test this statement by having a pendulum of a fixed length (say 80 cm.) and placing a drawing-pin through the string at 40 cm., 60 cm., etc., from the top.

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[1] Sir Flinders Petrie, writing in *Nature*, has suggested that the invention of the seconds pendulum is due to the Egyptians and not to Galileo. The length of the Egyptian cubit is 20·617 in. A square having sides of this length has diagonals 29·157 in. in length. This is exactly the length of a seconds pendulum making 100,000 swings a day. There are only 86,400 sec. in a day, and the length of a seconds pendulum is therefore greater.

CHAPTER VIII

THE LEVER

For thousands of years man relied entirely on his own physical strength for lifting and moving large stones, animals, etc. In their games and fights with each other, and in their encounters with wild animals, men knew their physical limitations. By joining forces they could move or lift much larger weights.

Man is a 'thinking animal' and in course of time he has thought out means of utilizing natural products and physical forces. He found it easier to roll or drag heavy bodies than to carry them. In carrying heavy logs over his shoulder he discovered that there was one position of the log better than others and really gained the concept of the centre of gravity (see p. 85). He had elementary ideas of inclined planes and levers, for he had found out that it was easier to zigzag his way up a hill than to struggle up the shorter but steeper road. He may have seen horned animals levering bodies with their horns, and copied their example by placing a piece of wood under a log or stone and moving it along (Fig. 71). The lever and the inclined plane are two different types of machine.

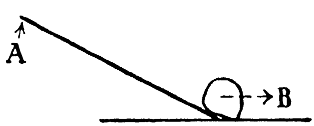

Fig. 71

To move a log by means of a lever a force has to be applied at A. The force applied multiplied by the distance that the body is moved in the direction of the force is the measure of work done. The unit of work

is the *foot-pound*, that is, the work done in raising a pound weight through a vertical height of 1 ft. A 10-pound weight moved through a vertical height of 10 ft. requires 100 foot-pounds of work to raise it.

Energy is the capacity to do work.

A machine is a means of transferring or transforming energy. Simple machines include the lever, the inclined plane, and the pulley. It is stated that 100,000 slaves were employed in building the Great Pyramid, the heavy stones being dragged up inclined planes of earth made alongside the building. The principle of the lever was discovered before the time of Christ.

Levers of the First Order. It is to Archimedes of Syracuse (287–212 B.C.) that we owe the lever. Archimedes is not only the "founder of the science of mathematics" but he is one of the greatest mathematical geniuses of all time. He balanced a bar (called the 'lever') over a support (called the 'fulcrum'). The bar balanced at a point called the 'centre of gravity' (Fig. 72). The centre of gravity is the point at which the whole weight of the body may be said to act. The centre of gravity of a circular piece of cardboard of uniform thickness is at the centre of the circle. In the case of a square piece it is where the diagonals cross.

FIG. 72

Archimedes found that equal weights placed at equal distances from the fulcrum balanced; but equal weights placed at unequal distances from the fulcrum did not balance, for that end where the weight was at a greater distance from the fulcrum went down.

A seesaw is an example of a lever, and a big boy and

a little boy can balance each other if they are at suitable distances from the pivot.

EXPERIMENT. To demonstrate the principle of the lever. First balance a graduated rod, which should be as rigid as possible, over a sharp edge which serves as the fulcrum. If a metre rod of uniform cross-section is used it will balance at the middle division (50). A triangular prism will make a good fulcrum.

Place a 20-grm. weight at, say, the 30-cm. mark (the middle of the weight should just cover the division)

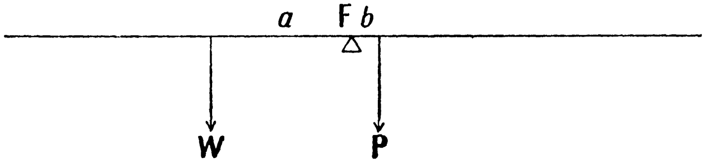

FIG. 73

and find where a 100-grm. weight has to be placed to restore the balance of the lever. One of the weights is called the 'weight' (W), and the arm on which it is placed is called the 'weight-arm'; the weight on the other arm of the fulcrum is then called the 'power' (P), and this arm is called the 'power-arm' (Fig. 73).

Let the distances of W and P from F be a and b respectively. Although these distances are each less than the half metre, they are called the arms of the lever, for the original conception of a lever was that it consisted of a rigid and weightless rod. In practice levers always have weight, but in the above case there is half a metre of lever on each side of the fulcrum, and they cancel each other out. The product of W and a is called 'the moment of the force W about the point F.' This tends to make the lever go down on the left-hand side. The product of P and b is called 'the

moment of force P about the point F.' This tends to make the lever go down on the right-hand side. When

$$Wa = Pb$$

the lever remains horizontal.

$$\therefore \qquad \frac{W}{P} = \frac{\text{length of power-arm}}{\text{length of weight-arm}}.$$

Regard 20 grm. as the weight and keep it suspended from the 30-cm. mark, that is, 20 cm. from the fulcrum. Then $Wa = 20 \times 20 = 400$. Now, giving P different values, complete this table:

P	b	Pb
100		400
50		400
20		400
10		400

P may be made up of two weights which may be suspended from the lever by cotton from different points so that the exact length of the power-arm of each power may be measured. Leaving the position and value of the weight unaltered, make a series of readings such as the following, and note if $Pb + P_1b_1$ is always equal to 400.

P	b	Pb	P_1	b_1	P_1b_1	$Pb + P_1b_1$
5	20	100	10	30	300	400

Instead of the words 'moment of a force about a point,' a single word, leverage, may be used. To lift a weight by means of a lever the leverage on the power side must be greater than the leverage on the weight side.

In lifting a boulder a pivot, which may be any hard substance such as a brick or stone, is placed near the boulder, the lever is depressed at P, and W is moved. In Fig. 74 the weight-arm is made small compared

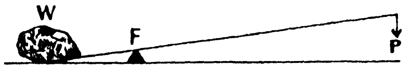

FIG. 74

with the power-arm, with the result that as

$$Wa = Pb$$

$$W > P,$$

or

$$P < W.$$

In such a case there is an advantage in using a lever, and since the lever is called a machine this advantage is called the 'mechanical advantage' of the lever. It is measured by the ratio $\frac{W}{P}$, or by the equal ratio

$$\frac{\text{length of the power-arm}}{\text{length of the weight-arm}}.$$

In general, when levers are used the power-arm is made greater than the weight-arm, but in the case of the balance, or weighing-scales, the manufacturers try to make the arms of the beam—the lever—of the same length.

The object to be weighed is placed in the left-hand pan, and weights are added to the right-hand pan until a nearly perfect balance or equilibrium is obtained. Since the arms are equal the weights in the right-hand pan give the weight of the object in the left-hand pan.

In all the above instances of levers the fulcrum is

between the weight and the power. These are described as 'levers of the first order.'

Other examples of levers of the first order are shown in the following figures:

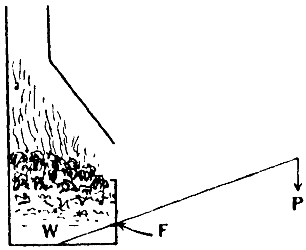

FIG. 75. A POKER

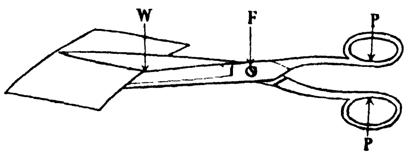

FIG. 76. PAIR OF SCISSORS

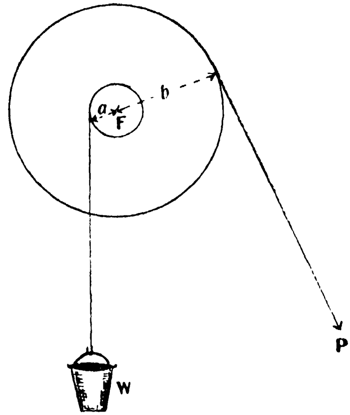

FIG. 77. WHEEL AND AXLE

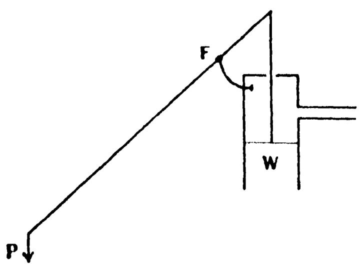

FIG. 78. A LIFT PUMP

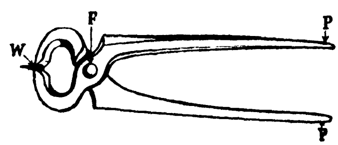

FIG. 79. A PAIR OF PINCERS

In all the above cases the power-arm must be longer than the weight arm so that the mechanical advantage is greater than 1, that is,

$$\frac{W}{P} > 1.$$

Levers of the Second Order. In levers of this kind W is between F and P. Compare the use of the lever shown in Fig. 74 with that illustrated in Fig. 80, in which the power is being applied upward.

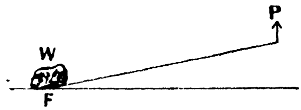

FIG. 80

Other examples of levers of the second order are illustrated below:

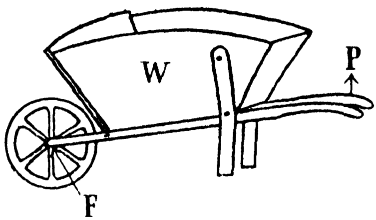

FIG. 81. A WHEELBARROW

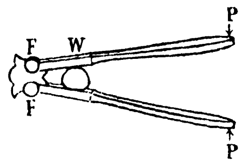

FIG. 82. NUT-CRACKERS HINGED AT ONE END

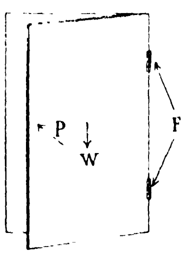

FIG. 83. CLOSING A DOOR BY PUSHING NEAR THE HANDLE

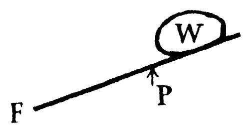

FIG. 84

Levers of the Third Order. *P* is between F and *W* in levers of this type (Fig. 84), which have a fractional mechanical advantage.

Examples of this type are sugar-tongs or coal-tongs

(Fig. 85) and closing a door by pushing near the hinges (Fig. 86).

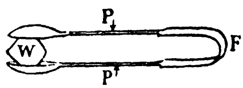

Fig. 85

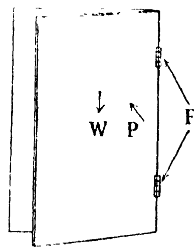

Fig. 86

Often we have a choice of levers when some weight has to be moved.

EXERCISES

1. Find the centre of gravity of (*a*) a ruler, (*b*) a circular sheet of cardboard, (*c*) a square sheet of cardboard, (*d*) a triangular sheet of cardboard (try to reason this out from the result obtained in (*a*)), (*e*) an irregular sheet of cardboard. Confirm your results by balancing each sheet at its centre of gravity on the end of a knitting-needle or a pin.

2. Fit up a lever of the first order using a metre rule. By means of it find the weight of (*a*) a metal cube, (*b*) an inkwell.

3. Find the weight of a metre rule by the principle of the lever.

4. Examine a balance, and reason out a method of finding the true weight of a body if the two arms are of unequal length. Compare the weight so obtained with the weight obtained by using another balance which is regarded as accurate.

5. A metre rod carries at its two ends weights of 50 and 100 grm. respectively. Calculate the position of the fulcrum for the rod to remain horizontal. Confirm by experiment.

CHAPTER IX

FIRE

EVERY house in a civilized country contains provision for either a coal, gas, or electric fire. Of all living things human beings are the only ones who know how to make fires. This shows our marked superiority over monkeys, lions, bears, and all the other animals.

This knowledge has been gained gradually. Thousands of years ago men, like animals, had to do without fire, and in consequence many froze to death.

In cold weather and at nightfall they hid themselves in caves, and so were warmer and safer from the attacks of animals than if they had slept in the open. The first people who lived on the earth were probably afraid of fire, as are many animals; it was a source of danger to them. Forest fires would break out, and the dancing flames and the flying sparks following them would make them think that they were being pursued by some evil spirit, for sometimes they were burned. Some people witnessed volcanic eruptions, and perhaps they always associated fire with destruction.

Wild animals, especially wolves, approached man's encampments in search of food. They rarely passed fire, however hungry they were. A brand from the fire thrown at them frightened them away for a time (see *White Fang*). January was called the Wolf-Month by the Anglo-Saxons, and this reminds us, firstly, of the presence of wolves in this country (until the reign of Edgar?) and, secondly, that January and February

are the two months in the year when there is a big shortage of food, and, being unable to secure an adequate supply, animals die in large numbers, or live by attacking other equally large or even larger animals, including man.

We can only speculate as to how fire came to be used, and such speculations may be far from the truth. But possibly a hungry hunter had to eat some burned flesh, or maybe the savoury smell attracted him. On tasting, he decided that the burnt flesh was preferable to raw meat. You should read Charles Lamb's amusing essay on "Roast Pig" to learn how the son of the swineherd Ho-ti introduced roast pork into China long ago.

A people with a knowledge of fire made rapid advances in civilization. They could cook their meat and provide a change from raw food, they were kept warmer, and instead of going to bed when it was dark they made a big fire and sat round it. They began to have more intercourse with each other, and began the art of story-telling. No wonder the gift of fire was highly valued and whenever a new Greek city was established the Mother City made a gift of fire to the daughter colony. There was always plenty of wood to keep the fires burning. Peoples could now spread over wider stretches of country, for they were able to keep themselves warm in colder lands. When the ruins of ancient cities are excavated evidences of fire are often found—ashes, burnt wood, pottery which had been burned in the fire, etc. But in a fireless age people lived on raw food, they were in constant danger from wild animals, especially in the night-time, and in danger of dying of cold unless they had plenty of skins

of animals to cover their almost bare bodies. There was little conversation among them, and what there was mainly had reference to the method of securing more food. There was little society, probably no story-telling, and only the lowest standard of living. The discovery of fire brought stupendous changes, and caused rapid improvements in civilization and a still greater conquest over Nature. Sir James G. Frazer has collected in his book *Myths of the Origin of Fire* the legends and the traditions of fire which were, or are, current among primitive peoples in different parts of the world. In the Prometheus legend the hero stole fire from Zeus in heaven and brought it to earth concealed in a stalk of fennel. For this he was punished by being bound to a rock in the Caucasus with an eagle gnawing at his vitals. According to many traditions fire was stolen by an animal. The Nootka Indians, who live near the north-west coast of America, believe that it was stolen from the woodpecker, its custodian, by the deer, assisted by the periwinkle. According to Breton folk-tales the gift is attributed to the wren, or to the robin, who singed his feathers while carrying it and thus acquired his red breast.

It was a great achievement to be able to produce fire at will. A man who was very cold used then, as now, to warm himself by rubbing his hands together or by clapping his hands on the opposite shoulders. One does this almost by instinct. It causes heat but not fire. In chipping stones to make javelins, knives, axes, etc., men would feel that hammering, or percussion, produced heat. Sometimes sparks would flash, and the foggy mind of the savage would decide that fire was in the stone. The commonest way of producing

fire was by friction, or rubbing two things together. Test these statements:

(1) Cold hands rubbed or clapped together become warm.
(2) Two pieces of wood rubbed together become hot and may even start to burn.
(3) Two stones knocked against each other become hot and sparks may be seen. If these sparks are caught by some dry wood-dust, paper, or shavings a fire may be started.
(4) If you are in the workshop get permission to grind your knife on the grindstone. Why is water run on to the stone?

The earliest way of making fire was that of rubbing two pieces of wood together, but the method is an arduous one, and the best results are obtained when a pointed stick is rubbed along a groove in another piece of wood or when it is rotated by the hands with the point in a hole in the wood (Fig. 87).

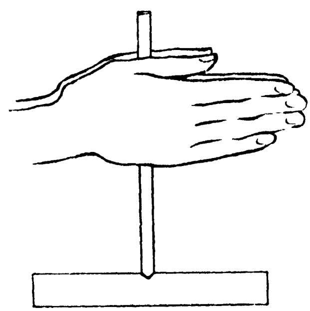

FIG. 87

Thus man ceased to be afraid of fire, and began to produce it at will, and to realize that though it was a good servant it was a bad master. Later fire was produced from flint (a rock) and steel. The flint was struck by the steel and the spark was caught on a piece of tinder, generally made of charred linen. This was the method in vogue until about 100 years ago, when matches were invented.

When man secured a fire after much labour it was

important to keep it alive. In ancient Roman mythology Vesta was the Goddess of the Hearth or the Home, and her temple stood in the Forum and contained the sacred fire which Æneas was believed to have brought from Troy. This fire was watched by the Vestal Virgins who guarded the Temple, and if by any chance it was allowed to go out it could only be relighted by the *pontifex maximus* by means of the flame produced by the friction of two pieces of wood.

Fires are kept alive by adding to them substances which will burn readily. These must be plentiful and cheap. Such matter is called 'fuel,' and is said to be 'combustible.' Wood, peat, coal, coke, and oil are the commonest fuels. At first rotten branches, leaves, straw, etc. were used; later trees were cut down for the purpose and after being left for a long time to dry were split or cut up. Wood is still used, not only in countries which do not possess coal, but also for starting a fire in those countries which have coal. Wood was the principal fuel throughout the seventeenth century and during the early part of the eighteenth century. A large amount of wood was also used in the blast-furnaces to get the iron out of the ore. Forests almost disappeared, and in the reign of Elizabeth Parliament passed legislation to stop the erection of more blast-furnaces. Then began the reign of "King Coal." You know what coal is, and that it is dug out of the ground. At the present time hundreds of thousands of men and youths spend their lives in the bowels of the earth getting coal. This fuel is only found in a few places in certain countries, and, while there is always the possibility of finding coal in many unsuspected places, the fact remains that coal can never be replaced.

Even though the changes which produced coal in past ages are operating to-day, we are using coal much faster than it can possibly be produced in Nature. Italy has no coalfields, whereas at the present time England, Scotland, and Wales have large supplies, and the coalfields of the Midlands and North have been worked on a large scale since 1750. Most of the coal has been formed through great forest trees and their fallen leaves sinking into, or becoming submerged by, the sea and then becoming covered and pressed down by heavy layers of sand and water. The internal heat of the earth and the pressure have gradually changed the wood to coal. The change may have extended over hundreds of thousands of years. During this transformation large quantities of gases have been produced, and when a coal-mine is being worked these gases ooze out of the coal. The resulting mixture is called 'fire-damp,' and is responsible for many of the explosions in coal-mines.

Finding a coal-seam is sometimes a very easy matter and at other times a difficult one, and our great mining engineers and geologists are always consulted in the sinking of a new shaft.

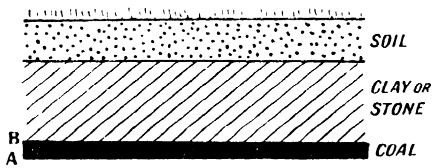

FIG. 88

Sometimes the layers of soil and rock under the grassy surface are nearly horizontal (Fig. 88). At other times the layers are tilting or dipping (Fig. 89).

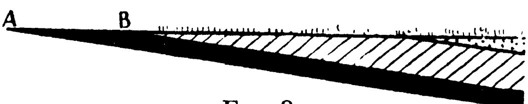

FIG. 89

Where the coal comes to the surface at AB it is

called an outcrop. A farmer sometimes exposes one of these outcrops when ploughing, or the thin layer of soil covering an outcrop may be kicked or washed away. Such coal would be the first to be used, but as a rule it is not very good. Later holes were dug, the soil and clay being removed to expose the coal (Fig. 90). When this became difficult, dangerous, or expen-

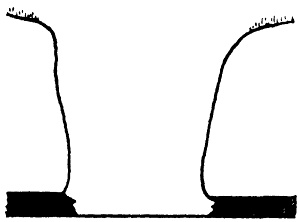

FIG. 90

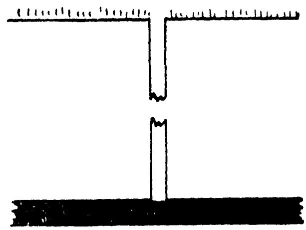

FIG. 91

sive, a shaft was sunk and the coal was broken up and sent to the surface in baskets or boxes, which had to be dragged first to the bottom of the shaft by boys (Fig. 91).

Winding machinery was later installed to lower the men down and to draw the coal up. To prevent the roof of a mine falling in it is held up by pit-props made of wood (Fig. 92) or steel. When the coal has been got away the miners remove the props as they retire.

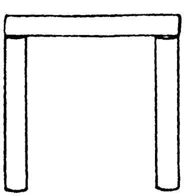

FIG. 92

Often the coal is loosened by means of explosives. There is a network of tram-lines inside the mine so that the coal can be moved about in the wagons very easily and quickly. As it is pitch dark in the mine the miner uses a lamp. This lamp is an improvement on the safety-lamp invented by Sir Humphry Davy. You will understand why it is called a 'safety-lamp' after

reading Chapter XI. Previous to Davy's invention a great many explosions occurred in mines owing to the use of candles, and many lives were lost. The air inside a mine becomes very poisonous, not only because the miners are using up the pure air, but also because of the fire-damp which is constantly oozing out of the coal as it is laid bare. For these reasons great attention has to be paid to the ventilation of a mine. The workings are very extensive, and some of the miners have to walk thousands of yards underground before they reach their work at the coal-face.

Living inside the mine, sometimes for months or longer at a time, are the pit-ponies, which are used to pull the tubs of coal to the bottom of the pit shaft. Sometimes they stay in the mine for years and go blind as a result of the darkness. Gradually they are being displaced, and soon they will be a memory of the past.

Over two hundred million tons of coal are raised in Great Britain annually. Much is exported, and the rest is used as fuel and for converting into coal-gas and coke.

Coal is a very wonderful substance. If you remove a half-burnt piece of coal, or cinder, from the fire, you will see that it has lost its shiny appearance, is greyish-black in colour, and is full of holes. It is coal in this state (now called 'coke') that is used in blast-furnaces. Coke is made on a large scale at the gasworks. The coal is placed in retorts, so that air cannot get to it, and heated very strongly. The gas and tar are removed and the coke is left behind. Coal does not burn easily like paper, so in making a fire paper and wood are placed in the grate first and then covered with small

pieces of coal. The paper is lighted and soon the wood gets on fire, and the heat of the burning paper and wood starts the coal burning. To get the best results the paper, wood, and coal are arranged loosely so that air can circulate among them, for air is just as necessary as coal. A 'blower' of iron is sometimes placed in front of the fire; this helps to develop a draught, which is compelled to pass through the burning wood and coal. Or a pair of bellows may be used. When it is found that the fire is nearly out a poker is put between the bars of the grate and the cinders are lightly lifted up. Air can then circulate among the hot cinders, and the fire often revives.

At one time it was believed that a fire was put out by evil spirits inhabiting the chimney. So a poker was thrust in, which made with the bars the "Sign of the Cross"; at this the spirits were expelled and the fire revived.

It was not until the eighteenth century that man really discovered why a fire burned. First it was discovered that air was necessary, and later that only one part of the air, the oxygen, was required.

Light a candle and when it is burning brightly cover it with a glass cylinder. After a few seconds the inside of the glass becomes dimmed and the light goes out. No fresh air can get to the candle, and so the flame is extinguished (Fig. 93).

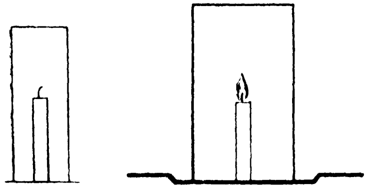

FIG. 93

Or place the candle on a plate and cover it with a lamp-glass. Put a piece of a match under the glass, as shown in Fig. 94, so that there is an entrance to the

glass at the bottom as well as at the top. Light the candle and you will notice that it continues to burn. Evidently it is getting a plentiful supply of air somehow. Now pour water into the plate so that the gap at the bottom is closed and no fresh air can get to the candle that way. In a short time the light goes out so that the supply of air has evidently been cut off although the glass is still open at the top. Cannot air enter this way?

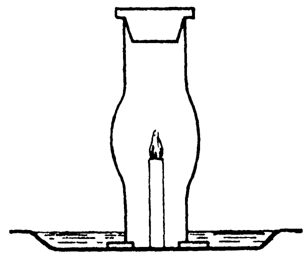

FIG. 94

To settle this point another experiment is necessary. Repeat the last experiment, and just before adding the water to close the lower entrance hold a lighted taper at the top of the glass. From the direction in which the flame is blown you will see that air is not entering the glass through this opening. Pour the water into the plate and see if air is entering at the top as the flame is beginning to languish. Before the flame expires take the T-shaped piece of cardboard shown in the sketch and place it in the opening at the top. It divides this entrance into two parts. Note that the flame begins to revive and it continues to burn indefinitely. Put the lighted taper at each entrance in turn and you will see that a current of air now enters down one side of the card and a current of used gas escapes by the other. By the simple device of dividing the hole with a piece of cardboard a continuous supply of air has been maintained within the glass.

Burning, or combustion, requires an adequate supply of air.

CHAPTER X

THE BUNSEN BURNER

The Bunsen burner is one of the most necessary pieces of apparatus in the laboratory. An electric light or an ordinary gas flame may be used as a source of light, but a Bunsen burner is nearly always used as the source of heat. Yet until Bunsen, who was born at Göttingen on March 31, 1811, and died at Heidelberg on August 16, 1899, invented his burner scientists had to manage with oil-lamps, charcoal fires, burning-glasses (lenses), and spirit-lamps as sources of heat. Sir Henry Roscoe, a great English scientist who was long associated with Bunsen, first as a pupil and then as a colleague, regarded him as one of the foremost chemists of last century. It is interesting to note that Columbus was a Genoese, Galileo an Italian, Newton an Englishman, and Bunsen a German. These facts serve to show that there are men of different nationalities engaged in the same great quest: the quest for truth.

Bunsen's discoveries were both numerous and important. A few examples of his work, such as you are able to understand, are briefly described. Bunsen's first discovery was that freshly made ferric hydroxide acts as a powerful antidote in cases of arsenical poisoning. The arsenic is rendered insoluble both in water and in the secretions of the stomach and therefore is ineffective. This is a matter of interest to all, as arsenical poisoning sometimes occurs. Besides being contained in rat poison, arsenic is present in the liquids

used in spraying fruit-trees, and in spite of rain some remains on the fruit when it is gathered. It is useful to know what antidote to get from the chemist when poisoning occurs.

Another of his important researches was into the nature of the compounds known as the cacodyl compounds. During the course of these experiments he lost the sight of his right eye, was nearly poisoned, and for days he hovered between life and death. But he recovered, returned to his problem, and ultimately brought it to a satisfactory conclusion. This work is mentioned to show that dangers sometimes confront the pioneer, and that heroic qualities must often be exercised.

A well-known invention of his was the Bunsen cell, or zinc-carbon battery. You are familiar with the Leclanché cell generally used to work an electric bell. Bunsen's cell was much more efficient than the Leclanché cell as it could be used continuously over a much longer period. It is not used much in these days of accumulators, but it can easily be fitted up in the laboratory. An outer glazed or glass vessel contains dilute sulphuric acid. Inside this is a porous pot containing concentrated nitric acid. A zinc rod is placed in the sulphuric acid, and a carbon rod in the nitric acid. When the exposed ends of the two rods are joined by a wire a current of electricity flows. As early as 1843 Bunsen showed that the electric current could be used as a means of illumination. Forty-four of his cells joined up in series gave, for the expenditure of 1 lb. of zinc per hour, a light equal in illuminating power to 1171·3 candles, "the brilliancy of which the eye can scarcely support."

But his best known invention was the Bunsen burner. While oil-lamps, spirit-lamps, charcoal fires, and burning-glasses had served useful purposes in the past, they could not approach the Bunsen burner for convenience, efficiency, and safety.

Bunsen was a shining example of a scientist who pursued science for its own sake; he never regarded it as a means to making a fortune. On one occasion when congratulated on having received some high mark of distinction he replied, "Ah, the only value such things had for me was that they pleased my mother, and she is now dead."

He had a very bad habit of dispensing with the crucible tongs, removing very hot crucible-lids by means of his forefinger and thumb. His fingers smoked, but he grinned and cooled them by pressing the lobe of his ear between his finger and thumb.

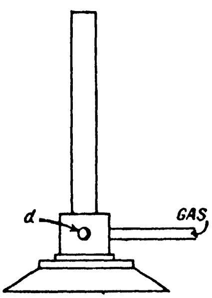

Fig. 95

Experiment. Examine carefully a Bunsen burner. A diagram of one is shown in Fig. 95.

Near the base of the Bunsen there is a collar which turns round and covers and uncovers a hole (*d*) in the long tube which is known as the mixing-tube. Light the Bunsen. When the hole is closed by the collar the flame is yellowish or luminous. Hold a piece of cold porcelain or a test-tube containing cold water in this yellow flame. It is covered with a black deposit of carbon. Turn the collar round until the opening is uncovered. The flame is now almost invisible and is described as a non-luminous flame. When a cold object is put into this flame it is heated but not

blackened. This is the flame that is always used in the laboratory unless you are advised differently. The enlarged figure below shows the principle of the Bunsen (Fig. 96). Unscrew the mixing-tube and examine the base of the Bunsen.

The gas enters at *a* and flows under a considerable pressure through the narrow aperture (*b*) into the mixing-tube (*c*). The rush of gas into this tube causes air to be sucked into the mixing-tube through the hole (*d*) in the collar. By regulating the rates at which the coal-gas and air enter the mixing-tube we can regulate the size, temperature, and colour, or luminosity, of the Bunsen flame.

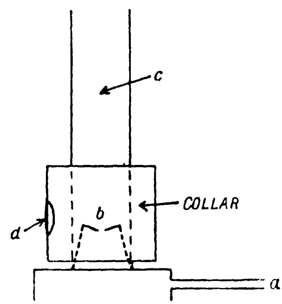

FIG. 96

In order to secure some practice in the use of the Bunsen, carry out the following experiments:

EXPERIMENT 1. Measure into an evaporating dish 25 c.c. of water. Place the dish on a tripod-stand covered with wire gauze or a sand-tray. Use a luminous flame of convenient size. Find the time to evaporate the water to dryness.

EXPERIMENT 2. Do not alter the size of the flame but turn the collar of the Bunsen so that a non-luminous flame appears. Now take the time to evaporate an equal amount of water.

EXPERIMENT 3. Heat a piece of platinum or platinum substitute in the Bunsen flame. (Remember always to use the non-luminous flame unless told to use the other.) Weigh the substance before and after the experiment.

EXPERIMENT 4. Pick up a piece of magnesium ribbon with a pair of crucible tongs and heat it in the flame.

EXPERIMENT 5. Heat a little sulphur in a deflagrating spoon until it gets on fire.

EXPERIMENT 6. Heat a piece of wood or a feather in a test-tube.

EXERCISES

1. Which of the substances used in Experiments 1–6 change their state when heated, that is, go from solid to liquid or from liquid to gas?
2. Which substances are converted into entirely new substances?

CHAPTER XI

THE EXPANSION OF SOLIDS, LIQUIDS, AND GASES WHEN HEATED

WE saw in the last chapter that heat causes certain changes in bodies:

(1) They change their state, that is, solids are changed to liquids and liquids to gases. These changes are called physical changes, as are the changes gas to liquid and liquid to solid.

(2) Some substances are completely changed into something else. These changes are called chemical changes.

(3) They may also get hotter, without either changing their state or undergoing a chemical change.

We shall have to refer to physical and chemical changes later. Meanwhile let us consider what happens to the size of a body when it is heated.

THE EFFECT OF HEAT ON SOLIDS

EXPERIMENT 1. Take an iron rod about 18 in. in length and $\frac{1}{4}$ in. thick (a retort stand may be used). Fix it at one end by putting a weight on it or having that end against the bench or wall. Rest the other end on a knitting-needle or a piece of glass tubing, suitably raised on wooden blocks. Fasten a paper indicator to the needle or tubing. Heat the rod

strongly by means of a Bunsen burner (Fig. 97). The rod expands, for the needle is turned round by the

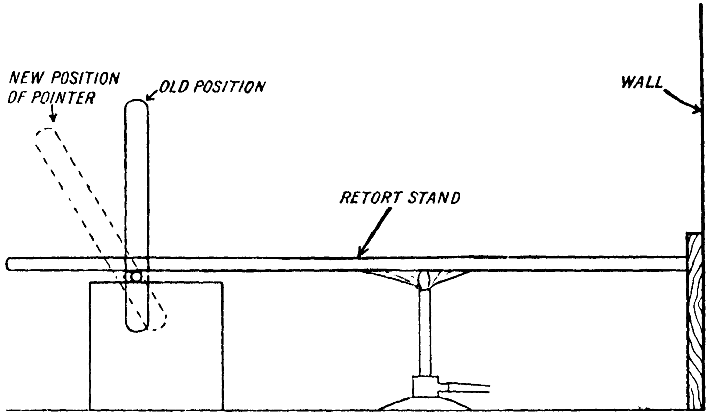

FIG. 97

iron rod rolling over it, and you see a movement of the paper index.

Let the apparatus cool; the rod evidently contracts, for the paper index resumes its original position.

Take the apparatus known as Gravesand's ring and ball (Fig. 98). See if the ball will pass through the ring.

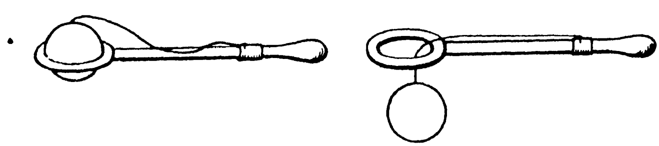

FIG. 98

Heat the ball in the Bunsen flame and then rest it on the ring. It will no longer pass through. What happens if the ball is left in this position for some time? Account for what you observe. Pour cold water over the ball. It now contracts and will again pass through the ring.

The force of expansion and contraction is enormous,

and can be used to snap a piece of cast iron quite easily. A piece of apparatus due to Tyndall may be used for the purpose. There is a metal bar with a screw at one end and a hole at the other. The bar, which is as shown in Fig. 99, fits into an iron frame. A cast-iron bar passes through the hole B, and the long bar AB is free to expand. Heat it strongly. Then turn A until the bar is held firmly in the frame. Let the bar cool in the air or put a wet cloth over it. As it cools it contracts, and the force of contraction is sufficient to snap the cast-iron bar which passes through B. A plan of the apparatus is shown in Fig. 100.

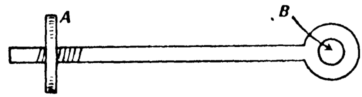

FIG. 99

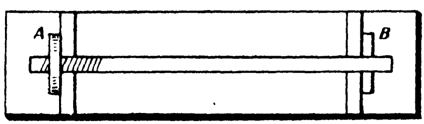

FIG. 100

Solids expand when heated, and provision must be made for this to take place or accidents may occur. Railway lines, which are fully exposed to the heat of the sun, expand in hot weather, so they are laid with short gaps between consecutive rails. Otherwise they might get buckled in hot weather and trains would be derailed. Tram lines are buried, and so do not get heated to anything like the same extent, and gaps are not necessary. But whenever there is a considerable change of temperature some provision must be made for change in size. For example, in the construction of the Forth Bridge (opened in 1890) about four feet was left for expansion in length.

Unequal Expansion of Solids. If strips of brass and iron are riveted together (Fig. 101 (i)) and heated in a

Bunsen the strips expand, but at different rates. For this to take place the strips must bend, the brass strip, which has the greater expansion, being on the outside and the iron strip on the inside (ii). On being cooled the bar becomes straight again. If the cold bar is placed in a freezing-mixture of ice and salt the bars will bend again, but this time in the opposite direction (iii).

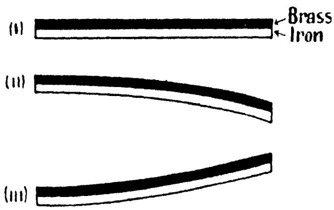

FIG. 101

Every scientific discovery may, in time, be applied to some useful purpose; and this principle of the unequal expansion of metals and alloys has been used to make clocks and watches keep good time during changes of temperature.

FIG. 102

Clocks. The simple pendulum consists of a metal bar at the lower end of which is a metal bob. We saw in Chapter VII that lengthening or shortening the pendulum alters the time of vibration and the clock 'loses' or 'gains.' In future pendulums will be made from an alloy (such as invar) which does not change its length with change of temperature, but at present many clocks are regulated by moving a screw at the bottom of the pendulum (Fig. 102) or by applying the principle of unequal expansion of metals and alloys (Fig. 103).

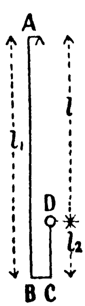

FIG. 103

In Fig. 103 AB and CD are lengths of different metals and D is the bob. The effective length of the pendulum is l—*i.e.*, $l_1 - l_2$—the pendulum being pivoted at A. On a hot day both

metals expand, AB downward and CD upward. By choosing suitable metals whose rates of expansion are known we may determine a suitable pair of lengths for AB and CD which are such that l can be kept constant, and so the clock will neither gain nor lose however the temperature alters.

In a watch the rim of the balance wheel is made of two different metals, with the result that as the radius of the balance wheel expands with heat the rim is bent inward (Fig. 104).

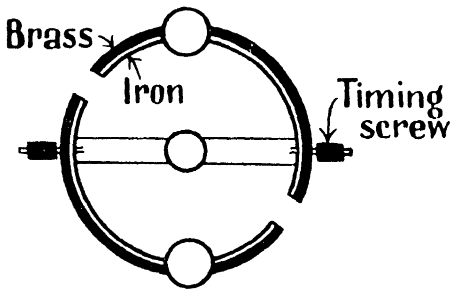

FIG. 104

THE EXPANSION OF LIQUIDS AND GASES

EXPERIMENT 2. Fit a flask with a rubber stopper carrying a glass tube, as shown in Fig. 105. Fill the flask and part of the stem with coloured water (a very dilute solution of potassium permanganate will do). Fit a paper scale behind the glass tube. Heat the flask over a wire gauze or sand-tray. Obviously the heat first reaches the glass, and as this expands the water is seen to drop in the stem. Eventually the heat reaches the water, which evidently expands more than the glass, for it rises in the stem and may overflow. Remove the Bunsen and the water falls in the tube—*i.e.*, it contracts on cooling.

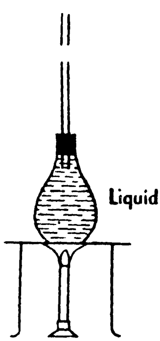

FIG. 105

Empty the flask, dry it outside, and invert it with

the open end of the stem dipping beneath the coloured water in a beaker (Fig. 106). Put your warm hands around the flask, or gently heat it with a Bunsen. Bubbles of air escape, showing that air (a gas), like water (a liquid) and iron (a solid), expands when heated. As the liquid in the beaker stops the expelled air, or any other air, from entering, coloured water must enter the tube on cooling to take the place of the air which has been expelled.

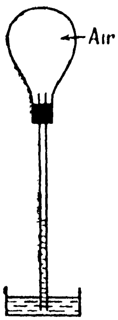

FIG. 106

Heat travels in three different ways:

(1) **By Conduction.** Hold a poker in a fire, or a short length of iron in a Bunsen flame. The other end will in time get hot. The particles of the iron have not changed their places, for if two chalk marks are made on the bar they do not change their relative positions—*i.e.*, the ratio of their distance apart to the whole length of the poker is the same when the poker is hot and when it is cold.

(2) **By Convection.** The radiators and pipes in the school hot-water supply do not move, but the hot water leaves the boiler and actually circulates through the radiator and the pipes and then returns to the boiler. Convection currents can readily be observed in the laboratory.

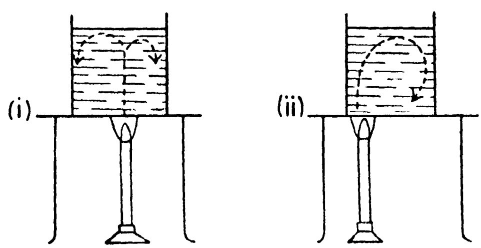

FIG. 107

Heat some water in a beaker and add a few crystals of potassium permanganate. The streams of colour will show you which way the water is moving. On altering the position of the Bunsen from the middle to one side of

the beaker it is possible to alter the direction of the current (Fig. 107).

The following experiment illustrates the convection of heat very satisfactorily. Fit up the apparatus, which is made from glass of a suitable bore, shown in Fig. 108.

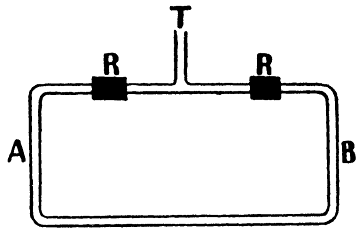

FIG. 108
R, rubber connexion; T, a T-piece.

Fill the apparatus with water and put a few crystals of potassium permanganate at T. Heat limb A and the coloured water flows from A through T to B. Heat limb B and the coloured water flows in the opposite direction.

In conduction heat is passed from particle to particle without the latter changing their relative positions; in convection the heat is conveyed by the movement of the hot particles themselves from one place to another.

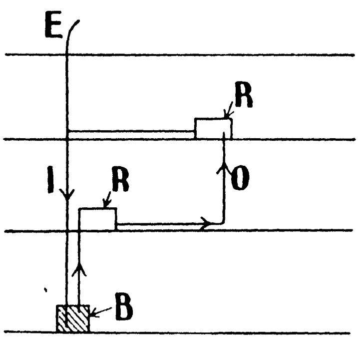

FIG. 109
B, boiler; R, radiator; E, expansion tube; O, outlet tube; I, inlet tube.

Heat is generally transmitted by gases in convection currents. Air in movement is called wind. The hot air at the equator rises, and colder air takes its place from the north and the south.

The heating of greenhouses, public buildings, some private houses, etc., is based on convection currents, or central heating. The water is heated in the lower part of the building and enters the outlet pipe, which is at the top of the boiler (Fig. 109).

It circulates round the building and re-enters the boiler by the inlet pipe, which reaches to the bottom.

(3) **By Radiation.** The sun heats the earth by radiation, and a fire heats a room mainly by radiation (Fig. 110).

The rays from the hot fire are radiated in all direc-

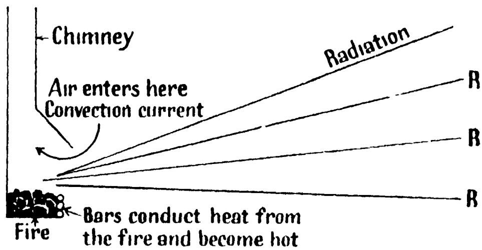

FIG. 110

tions, are absorbed by the solid or liquid bodies in their way, and are then re-emitted as heat. A fire-screen absorbs these heat-rays, and so prevents them from passing into the room. During an eclipse of the sun by the moon the latter cuts off the heat of the sun and absorbs it.

Metals are good conductors.

Water and air readily transmit heat by convection.

Water and air are, however, bad conductors. In Fig. 111 the test-tube is nearly full of water and a piece of ice, wrapped in wire gauze, has sunk to the bottom. The water at the surface may be heated until it boils, but the ice does not melt, showing how bad a conductor of heat water is. So are flannel and hay. Ice may be preserved for hours by wrapping it in flannel, and hot liquids may be kept hot by placing the vessels holding

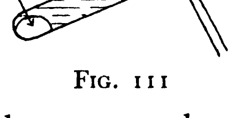

FIG. 111

them in a hay-box. Air also is a bad conductor, and double-windows, the space between being filled with air, are used in cold countries to keep the rooms warm.

Metals are good conductors, and so a metal teapot is generally provided with a handle of non-conducting material.

The Davy Lamp. Until the time of Sir Humphry Davy miners worked with naked lights and explosions

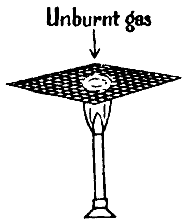

FIG. 112

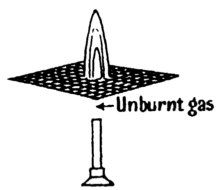

FIG. 113

were common. Davy knew that a gas, however explosive its nature, would not explode unless a certain temperature, known as the temperature of ignition, was reached. Light a match, blow out the flame, and hold the glowing end above a Bunsen burner from which gas is issuing. The gas does not light: the glowing match is not hot enough to ignite the gas. Now put a light to the Bunsen: the temperature of the flame is above the temperature of ignition of coal-gas, and so the gas burns.

Lower a piece of wire gauze into a flame (Fig. 112). The flame is pressed back but does not pass through the gauze. Put a light above the gauze. The flame now appears on both sides of it. In the first place when the flame was kept on the under side of the gauze some of the coal-gas passed through the gauze, which, however, conducted away the heat of the Bunsen

flame so that the temperature on the upper side of the gauze was not high enough to light this unburnt gas. In time the gauze would get hot enough to light this gas.

Vary the experiment as follows. Turn on the gas and hold the gauze a few inches above the Bunsen (Fig. 113). Light the gas above the gauze. The gas below the gauze does not burn, for the reason already given.

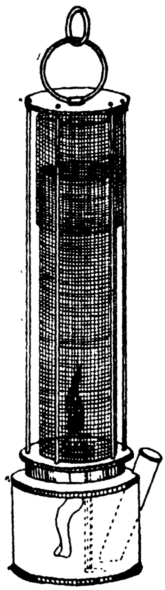
FIG. 114

Davy's lamp is essentially a lamp with a covering of wire gauze (Fig. 114). The air of the mine passes through the gauze and the lamp burns. When fire-damp enters the lamp there is a small explosion within the gauze, but the heat is conducted away by the metal and the temperature of the latter is not high enough to ignite the explosive mixture outside.

The lamps are locked when they are given out to the miners, and they can only be relighted by taking them back to a convenient central lighting station in a safe corner of the mine. An explosion in a Davy lamp puts the light out; this may cause a little inconvenience to the miner, but it is useful because it reveals the presence of fire-damp.

EXERCISES

1. Using a retort stand, show that a solid expands when heated.
2. Perform Gravesand's ring-and-ball experiment.
3. Describe or perform an experiment to show the force of contraction or expansion.
4. Show that water expands when heated.

5. Devise an experiment to show that glass and iron bars exactly alike in length and thickness conduct heat at different rates.

6. Discover if there are any convection currents in the laboratory. (When Bunsens are alight notice if any of the electric lights are swinging or hold a light to the bottom of the doors (when closed) or near an open window. If there is a fume-chamber or a grate near find which way the air in it is moving.)

7. Examine a radiator. What is the reason for its peculiar shape? Are there metal plates supplied with your radiators? If so, why? Feel the pipes connected to a radiator. Is the water going away from or back to the boiler? How do you know?

8. Show that water transmits heat well by convection but badly by conduction.

9. See if the temperature of a red-hot nail is above the temperature of ignition of coal-gas.

10. Examine a Davy lamp. Why should it not be allowed to stand in a draught when it is alight?

CHAPTER XII

SOME OF THE PROPERTIES OF BODIES: THERMOMETERS

SOME of the objects around you can walk—they are alive. Other things which cannot move about from place to place are also alive, for example, trees. Yet other things are apparently without life, for example, a stone. We can therefore divide bodies into two classes; a class consisting of living, or animate, things, and a class consisting of lifeless, or inanimate, things. In a later chapter we shall deal with living things, both animal and plant.

Examine a number of inanimate things—a stone, some water, a piece of iron (say a poker), glass—and try to describe them. For example, a piece of glass is hard to the hand; if you drop it it breaks into many pieces, and for this reason is said to be brittle; if you rub one of the sharp points over a knife-blade the latter is scratched, and so the glass is said to be harder than iron. You can see through it, and because of this property it is described as 'transparent,' a name derived from Latin words meaning 'appearing across.' The words hard, brittle, and transparent describe some of the properties of glass.

Next consider water. This is a very interesting substance. Water, milk, and lemonade can be poured from one vessel to another, and because of this they are called liquids. If you leave a bottleful of water out-of-doors on a cold night it will probably freeze and you

will be unable to pour it away. The frozen water is called ice, and it is said to be solid. To make ice liquid, so that it can be poured again, you will have to warm it, or thaw it. If you then pour it into a pan and put it on the fire it boils and will soon disappear. It has gone into a form of water that you cannot see—it has become a gas. So water can exist either as a solid, a liquid, or a gas. In some places the seas are frozen, and ships get stuck in the ice. If the people want water to drink they have first to melt the ice or snow. Most things behave like water. Even iron and gold, which are known to us as hard solids, can be made into liquids and even boiled, but the 'pan' containing them must be heated very strongly.

Consider the meaning of hot and cold. We sometimes say that it is hot in summer and cold in winter, and hot in Africa and cold at the North Pole, and cold in January and warm, if not hot, in July. We have cold baths in the morning and hot baths, for cleansing purposes, when we go to bed. But what do we mean by these two simple words hot and cold? A simple experiment will enable us to understand better the meaning of these two terms. Take three dishes, all alike and large enough to put both hands in. Place some hot water in the first dish; some warm or tepid water in the second; and some cold water in the third. Place your left hand in the hot water and your right hand in the cold water. After a few minutes put both hands in the dish containing the warm water. Which hand feels the warmer now? Most people who have tried the experiment say the right hand. Do you agree? It is not very easy to explain why this is so, but of course there is an explanation.

When the hands were put in the hot and cold water respectively the left hand felt hotter than before and the right hand felt colder than before, because the two hands were taking the same temperature as the water in which they were placed. When they are put into the middle dish the left hand loses some of its heat to the water and feels cold, and the right hand now gains heat from the warm water and so appears warmer than the left hand. Thus, while the hands are sometimes used to tell when a body is hot or cold, they are not very reliable guides. If a body is hotter than your hand heat will pass into your hand, and you will feel warm, or hot. If a body is colder than your hand you will experience the sensation of coldness on touching it. Before jumping into a hot bath people dip one hand in to see if the water is at the right temperature, and before taking a cold plunge people dip their toes in the water first. But neither hands nor toes can tell very accurately how hot a body is, and we are fortunate in possessing a little instrument that will do this for us.

This instrument is called a 'thermometer.' The doctor has a thermometer to tell when his patients have a temperature, or are in a fever. Of course, we all have temperatures—everything has a temperature—but when a doctor says a patient has a temperature he means that he has a higher temperature than a healthy person ought to have. The doctor's thermometer is rather small so that it can fit in his waistcoat pocket. It is not a suitable thermometer to use in your experiments. It would break, for instance, if you merely washed it in hot water. Neither would it be of any use to tell the temperature of a room, for it is only used to record temperatures between about 95° and 105°

Fahrenheit, and room temperatures never reach even the lower figure.

Examine the thermometer hanging up in the classroom. It is called a Fahrenheit thermometer after the man who invented it. It consists of a piece of glass first sealed and then blown out at one end. Inside is some liquid that can be seen easily. Usually mercury or coloured alcohol is used. The glass tube is fastened to a piece of wood on which there is a scale of readings. Breathe on the thermometer. The liquid rises in the tube, but descends when you stop breathing on it. The thermometer is so important, not only to scientists but also to 'the man in the street,' that it is worth while going into the history of this valuable instrument.

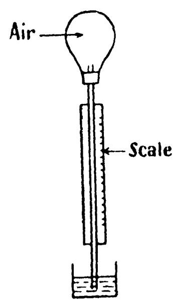

FIG. 115

The ancestor of our present-day thermometer was one made by Galileo (Fig. 115). In the beaker is coloured liquid. When hands are closed round the flask bubbles of air escape from the bottom of the tube. This is because air expands when heated, and so must leave the flask. The hands are removed and, as the bubbles cannot return, some of the coloured water enters the tube when the flask cools. Breathe on the flask or pour some warm water over it. The liquid in the tube falls, but rises when the flask cools to the temperature of the air.

Later Galileo constructed the thermometer shown in Fig. 116. Neither of these thermometers was very accurate. But in the eighteenth century improvements were made, and gradually more accurate thermometers were evolved. The method of manufacture may be copied in the laboratory.

STAGE I. Take a piece of glass tubing 10 in. in length. Use the tubing known as capillary tubing, which has a fine bore (Latin *capillus*, a hair). Melt one end in a hot flame and gradually it closes up. When the glass is very soft hold the tube vertically and blow

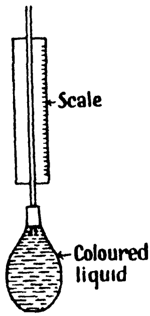

FIG. 116

FIG. 117

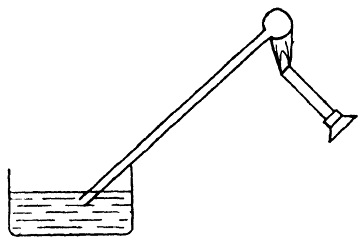

FIG. 118

gently down it and a bulb will appear. Stop blowing when the bulb is of a suitable size (Fig. 117).

STAGE II. Put the open end under some mercury or coloured liquid. Gently heat the bulb and notice that air bubbles escape through the liquid. Remove the flame and let the bulb, still kept in the same position, go cold. The air inside the tube contracts and some liquid enters the tube. By heating and cooling the tube alternately a number of times sufficient liquid may be drawn up to fill the bulb and part of the stem (Fig. 118).

STAGE III. The thermometer must next be graduated—*i.e.*, a scale must be put along the side of the tube. Put the bulb and part of the stem into melting ice contained in a glass funnel (Fig. 119). Any ice melting can run out at the bottom of the funnel. The liquid in the thermometer falls, and when it has descended as far as it will go a scratch is made on the

stem of the thermometer with a file. This is called the lower fixed point of the thermometer. It is marked o° on a centigrade and 32° on a Fahrenheit thermometer.

Now put the thermometer in the steam rising from boiling water. This is conveniently done by using a

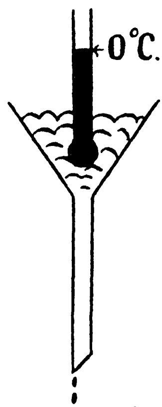

Fig. 119

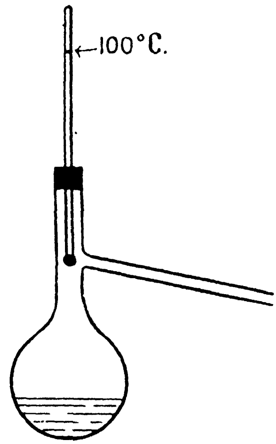

Fig. 120

flask with a long neck and a side outlet. The thermometer is lowered through the stopper in the flask so that the bulb and a considerable portion of the stem are in the steam (Fig. 120). The liquid in the thermometer stem rises. Mark the highest point reached with another file mark. This point is called the upper fixed point. It is numbered 100° on the centigrade scale and 212° on the Fahrenheit scale. The space between the two fixed points is divided up into 100 equal parts if we are making a centigrade thermometer and into 180 equal parts if we are making a Fahrenheit thermometer. Each part on both scales is called a degree, and to distinguish the two we speak of degrees centigrade and degrees Fahrenheit.

STAGE IV. Next, the tube is heated until the liquid inside boils or rises to the top of the stem; then it is sealed. There is now no air inside the stem, only the liquid and its vapour remaining. The completed thermometer may look like this (Fig. 121):

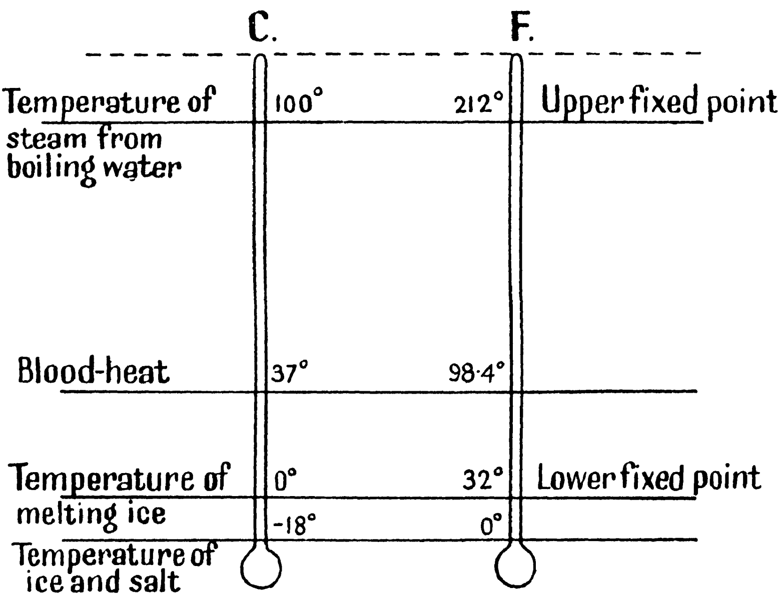

FIG. 121

Hang up the Fahrenheit thermometer in the form room, and read it at 9 A.M., 12 noon, and 3 P.M. every day for a week. Then arrange the readings in a table.

DAY	9 A.M.	12 NOON	3 P.M.
Monday . . .	57	60	63
Tuesday . . .	60	62	64
Wednesday . .	59	60	61
Thursday . . .	61	61	61
Friday . . .	56	54	54
Saturday . . .	53	57	61

N.B. On Monday morning the reading of the thermometer (called the temperature) was 57° at 9 A.M. As the school warmed up it rose to 60° and then to 63°. Graph these temperature results in the way shown in Chapter VI.

The thermometer illustrates very well how evolution, or development, or improvement, takes place in most, if not all, of man's inventions. The earliest thermometers were introduced into England by Boyle. They contained alcohol in a closed tube from which the air had been expelled. They were graduated, but not very accurately, for without a thermometer no one could prove that the melting-point of ice, or any other solid, was constant; but in 1670 Boyle proposed that melting ice should be the starting-point in graduating thermometers.

In 1701 Newton constructed a thermometer in which linseed oil was substituted for alcohol. His two fixed points were the melting-point of ice and the temperature of the blood of a living animal.

In the same year M. Amontons showed that pure water boils at a constant temperature.

Gabriel Fahrenheit (born at Danzig in 1686, died 1736) marked the lower fixed point of his thermometer — 90° (the temperature of ice and salt, which he thought was the coldest temperature conceivable) and the upper fixed point 90° (blood heat). In 1714 he changed his numbers to 0° and 24°. These degrees were too large, so when in 1720 he brought out the first mercury thermometer he used a new scale, the one that is still used in the thermometers that bear his name.

EXERCISES

1. Name a body which is hard and brittle, another which is cold and wet, another which is wet and heavy, another hard and heavy.

2. Take an exercise book and move it quickly past your face, or get some one else to fan your face. What causes the cool sensation?

3. Why should a doctor's thermometer not be washed in hot water?

4. Examine the temperature readings taken during last week. Draw a graph showing how the temperature varied during Monday. What was the average temperature between 9 A.M. and 3 P.M.?

5. What was the average temperature at 9 A.M. last week?

6. Make a thermometer.

7. Without watching the movement of the liquid in the stem of a thermometer, how could you find the highest and lowest temperatures recorded during any interval of time—for example, during the night-time?

CHAPTER XIII

MEASUREMENT OF HEAT: MELTING-POINTS AND BOILING-POINTS

A THERMOMETER measures the temperature of a body; it does not tell us how much heat there is in a body. A baby and a man have the same temperature, but the man contains much more heat than the baby.

An instrument that is used to measure heat is called a calorimeter, which in its simplest form consists of a metallic vessel (generally of copper). The unit of heat is the calorie. This is the amount of heat required to raise the temperature of 1 grm. of water through 1° C. Thus, raising 100 grm. of water from a temperature of 60° C. to 100° C. requires $100 \times 40, = 4000$, calories. The British Thermal Unit (B.T.U.) is the amount of heat required to raise the temperature of 1 lb. of water through 1° F.

Heat given to a body to raise its temperature is given out when it cools. The hot water in the radiator cools —*i.e.*, gives out heat—as it circulates through the pipes.

EXPERIMENT ON THE TEMPERATURE OF MIXTURES. Put 50 c.c. of water into a calorimeter. Rest the calorimeter on corks in an outer container to prevent loss of heat by convection currents. Take its temperature (14° C.). Heat 50 c.c. of water in a beaker. Take this temperature (100° C.). Pour this boiling water into the water in the calorimeter, and stir carefully with a thermometer. Notice the reading of the thermometer at its highest point (57° C.). This temperature

is only reached temporarily and then the liquid begins to cool.

In rising from 14° C. to 57° C. the 50 grm. of water gained 50×43, $= 2150$, calories.

The boiling water, in cooling from 100° C. to 57° C., gave up to the cold water 50×43, $= 2150$, calories.

Instead of adding 50 c.c. (= 50 grm.) of boiling water to the water in the calorimeter, put in a 50-grm. brass weight. First hang it by a piece of thread in some boiling water, and after giving it sufficient time to rise to 100° C. quickly dry it and lower it into the calorimeter containing 50 grm. of water at 14° C. Take the resulting temperature.

The amount of heat required to raise the temperature of 1 grm. of a substance through 1° C. is called its 'specific heat.' That of water is used as a standard, its specific heat being regarded as 1. That of copper is ·1. In the last experiment:

Weight of water in the calorimeter	= 50 grm.
Weight of brass	= 50 grm.
Initial temperature of water	= 14° C.
Initial temperature of brass	= 100° C.
Resultant temperature of water	= 22° C.
Let the specific heat of brass	= s calorie.

Now 1 grm. of water in rising through 1° C. requires 1 calorie, and 1 grm. of brass in cooling through 1° C. loses (by definition) s calorie. Therefore,

Heat gained by water, in calories,

$$= 50 \times (22 - 14)$$
$$= 50 \times 8 = 400.$$

Heat given up by the brass, in calories,

$$= 50 \times (100 - 22) \times s$$
$$= 50 \times 78 \times s.$$

These two quantities must be equal.

$$\therefore \qquad 50 \times 78 \times s = 400,$$

$$i.e., \qquad s = \frac{400}{50 \times 78} = \cdot 1 \text{ (nearly)}.$$

In this experiment we used 50 grm. of water and a 50-grm. weight of brass. In practice we can use any convenient weights of water and brass, marble, etc.

Melting-points and Boiling-points. In the previous chapter the temperature recorded when the bulb of the thermometer was placed in melting ice was stated to be the melting-point of ice (0° C.) and the temperature recorded by a thermometer held in the steam from boiling water was described as the boiling-point of water (100° C.). All boiling-points can be obtained in this way. A convenient piece of apparatus is shown in Fig. 122.

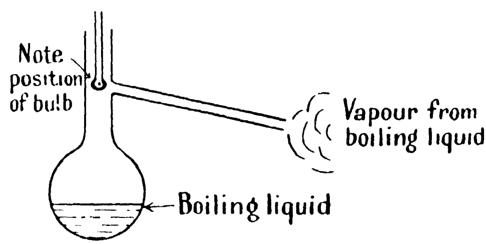

FIG. 122

EXPERIMENT. Melting-points are not found quite so easily. Fit up the following apparatus (Fig. 123).

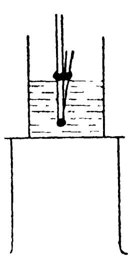

FIG. 123

Fastened to the thermometer by a rubber band is a narrow glass tube. It is made by drawing out a piece of softened glass, cutting off the portion a, and closing the end at b in a Bunsen

flame (Fig. 124). A narrow tube uses very little of the substance. A small test-tube may also be used.

FIG. 124

The water in the beaker is gradually heated and stirred by means of the thermometer. The melting-point is reached when the substance changes in appearance—*e.g.*, white paraffin wax becomes colourless.

Remove the Bunsen and continue to stir the water in the beaker. Try to find the temperature at which the wax, etc., again solidifies, or sets hard.

EXERCISES

1. Mix together 50 grm. of water at room temperature and 50 grm. of water at boiling-point. Find the temperature of the mixture.
2. Find the specific heat of marble.
3. Find the specific heat of iron, copper, or lead.
4. Find the specific heat of sand.
5. Explain how the difference of the specific heats of sand and water affects the climate of a place. Why is this difference important to a farmer? Are the specific heats obtained in Questions 2, 3, and 4 the same?
6. Find the melting-point of wax.
7. Knowing that ice melts at 0° C., see whether your thermometer is accurately graduated.

CHAPTER XIV

SOLUTION AND CRYSTALLIZATION

SOLUTION

WHEN a little salt is added to water it soon disappears; so does soap in hot water. The salt and soap are said to dissolve in the water. The salt water is apparently unaltered, but you can easily prove that the salt is still there by tasting the liquid. The soap has changed the appearance of the water and so there is no need to taste the liquid to learn what has become of the soap. The two liquids, salt water and soapy water, are now termed solutions. The water is called the 'solvent' for these two substances; the salt and the soap are termed 'solutes.' Thus:

SOLVENT	SOLUTE	SOLUTION
Water	Salt	Salt solution
Water	Soap	Soap solution

Water is the best known solvent and will dissolve many different substances, such as soap, soda, sugar, and ink powder. It will not, however, dissolve everything—*e.g.*, it will not dissolve quicksilver, silver, or gold. All liquids are solvents for something, but no liquid is a solvent for everything. How can we find whether, say, potassium dichromate, glass, or sulphur, will dissolve in water?

First try a single small piece of potassium dichromate. Powder it and drop it into some water in a test-tube. Shake up the mixture. The powder disappears and therefore must be dissolved by the water—it is said to

be 'soluble' in it. Further, the liquid becomes reddish in colour, and on touching the tongue with a glass rod that has been dipped in the liquid you will notice that it has a sharp taste. Go on adding more potassium dichromate. The liquid becomes still redder and at last, however vigorously you shake the test-tube, some red powder remains undissolved—evidently a solvent will not dissolve an unlimited amount of a solute. The solution is said to be saturated. When you can see the powder dissolve, or when the liquid remains coloured after the undissolved powder has settled, you can decide at once that the powder is soluble in water. But can the solute be recovered?

EXPERIMENTS. 1. Fit up the apparatus shown in Fig. 125. A circular filter-paper—*i.e.*, an unsized

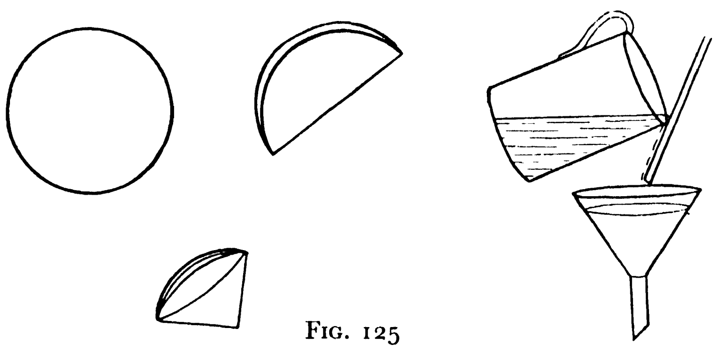

FIG. 125

paper—is folded, first in halves, then in quarters. Fit this in the funnel so that three folds of paper are on one half of the funnel and one fold only on the other. Wet the paper and see that it fits closely to the glass. Put a beaker or an evaporating dish under the funnel. Carefully pour the liquid into the filter-paper, or, better, pour it down a glass rod and so avoid spilling it (Fig. 125). It runs through the funnel. Any specks

of dust and any undissolved potassium dichromate are kept back in the filter-paper. (Other substances may be used in the funnel for quick and rough filtering—*e.g.*, a piece of cotton wool or asbestos will often do. It is because the hairs inside the nose keep the dust particles from entering the lungs that you should breathe in through the nose.) The liquid which runs through the filter-paper is called the filtrate. Heat the dish on wire gauze resting on a tripod stand: or a sand-tray may be employed (Fig. 126). Use a non-luminous flame. The liquid soon boils, the water is evaporated, and a reddish powder, the potassium dichromate, is left behind.

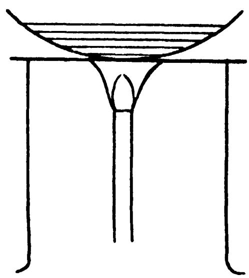

FIG. 126

This is the usual method of finding whether a substance is soluble in a liquid.

2. Now discover if salt, soda, sulphur, manganese dioxide, sand, saltpetre, etc., are soluble in water. So that there will be no doubt as to your conclusions, first evaporate a little tap-water in order to see if it has anything dissolved in it. If after evaporation you cannot rub any residue out of the dish on your finger, you may safely conclude that there is very little if any there. Tabulate your results as follows:

SUBSTANCE	SOLUBILITY IN WATER
Soda	
Salt	
Sulphur . . .	
Manganese dioxide .	
Sand	
Saltpetre . . .	

In the second column you should write 'very soluble,' 'fairly soluble,' 'slightly soluble,' or 'insoluble' according to the results of your experiments.

As a further experiment see if sulphur is soluble in carbon disulphide. This liquid is very inflammable and the Bunsen should be turned out during this experiment. Carbon disulphide boils at 46° C., and when poured on to the hand will quickly evaporate. Catch the filtrate on a large watchglass and, instead of evaporating it over a Bunsen flame, let it evaporate at the temperature of the room. If possible examine the residue under a magnifying glass. Have the particles any definite shape? If so, draw the shape.

Having discovered that water will dissolve many different substances, some very easily and others only in very small quantities, the next question is, "How much of the substance will it take to saturate a given quantity, say 100 grm., or c.c., of water at the temperature of the room?" Try both of the following methods.

3. Get a beaker and a large test-tube fitted with a stopper or a cork. Measure into the test-tube 25 c.c. of water, which weighs 25 grm. Weigh the test-tube in the beaker. Now add salt to the water in half-gramme or quarter-gramme portions, replace the stopper after each addition, and shake the test-tube until the salt disappears. Continue to add salt as long as it appears. At length a little salt remains over. The solution is now said to be saturated. Weigh the whole apparatus again. The difference between the two weights gives the weight of salt contained in the saturated solution, say x grm. Therefore 25 c.c., or grm., of water at the temperature of the room dissolve x grm. of salt. Therefore 100 grm. of water at the

temperature of the room will dissolve $4x$ grm. of salt.

This value ($4x$) is said to be the solubility of salt in water at the temperature of the room.

The result is not quite accurate as the tiny portion of salt left over has been counted in the result. A better way would be to proceed as follows:

4. Make a saturated solution of salt in water and pour the whole liquid, including the undissolved salt, into a filter-paper. The filtrate is saturated salt solution. If there is no time to filter, pour some of the clear liquid into a weighed evaporating dish and weigh again.

Evaporate slowly over a small flame, using wire gauze, sand-tray, or water-bath. Weigh the dish and residue.

Readings

1. Weight of evaporating dish when empty . .
2. ,, ,, ,, and saturated solution . .
3. ,, ,, ,, and residue . .

The weight of solution is obtained by subtracting reading 1 from reading 2 (say x grm.).

The weight of salt left is obtained by subtracting reading 1 from reading 3 (say y grm.).

If the weight of solution and the weight of salt in the solution are known it is easy to find the weight of water in the solution—namely, $(x - y)$ grm. Therefore $(x - y)$ grm. of water dissolve y grm. of salt.

1 grm. ,, dissolves $\frac{y}{x-y}$ grm. of salt.

100 grm. ,, dissolve $\frac{y}{x-y} \times 100$ grm. of salt.

FURTHER EXPERIMENTS. Find by the methods described above the solubilities of salt, potassium dichromate, and saltpetre at room temperature. Enter up your results as follows:

SOLUTE	SOLUBILITY IN WATER AT ROOM TEMPERATURE (° C.)
Common salt . . .	
Potassium dichromate. .	
Saltpetre	

It will be noticed that solubilities differ very considerably for different substances. Some substances—*e.g.*, glass—are almost insoluble in water. Glass panes are hardly affected by the rain that falls on them over a period of many years.

One question still remains to be answered; namely, does the temperature of the water make any difference?

EXPERIMENT. Make a cold, saturated solution of saltpetre. Then heat the solution until it boils and add small portions of saltpetre. They continue to dissolve for quite a time, showing that hot water will dissolve more solute than cold water. If time permits find the solubility of the above three solutes in boiling water. Put your results side by side as indicated in this table:

SOLUTE	SOLUBILITY IN WATER AT ROOM TEMPERATURE (° C.)	SOLUBILITY IN BOILING WATER
Common salt . .		
Saltpetre . .		
Potassium dichromate		

Crystallization

The results tabulated above show that some substances are more soluble in hot water than in cold; but what will happen when a hot saturated solution, say of copper sulphate, whose solubility in 100 grm. of water at 100° C. is 203 grm., is cooled down to room temperature, say, 15° C., at which its solubility is only 40 grm.? Even without performing an experiment most persons would rightly guess that the extra 163 grm. would be thrown down, or deposited. A saturated solution cannot hold more of the solute than it takes to saturate it; sooner or later the extra load is expelled, and it appears in beautiful crystalline forms. As the crystals are often very small it is not easy to tell their exact shape, but chemists have made the following discoveries:

1. All the copper sulphate crystals are of the same shape.
2. They are bounded by plane faces, and the angles between two corresponding faces are always the same.
3. By placing a small crystal in a bath of saturated copper sulphate solution, and turning over the crystal daily, it will grow bigger, when its shape will be as shown in Fig. 127.

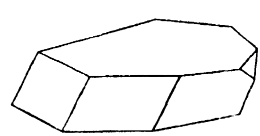

Fig. 127

4. Very pure crystals can be obtained by taking the first crop of crystals, dissolving them in a small amount of distilled water, and crystallizing again in the usual way.

5. Alum crystals can readily be obtained, but they have their own characteristic shape (Fig. 128).
6. A saturated solution, cooled suddenly, gives small but pure crystals.
7. Many crystals occur naturally—*e.g.*, quartz, salt, marble. The shapes of some crystals should be known—see Fig. 129.

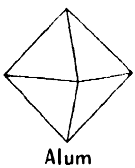

FIG. 128

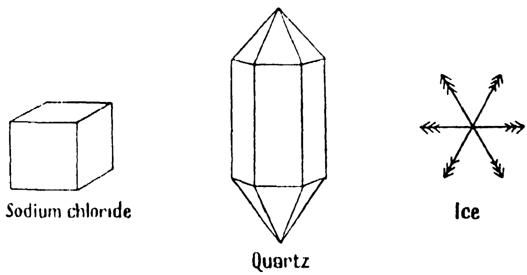

FIG. 129

EXPERIMENTS. Make crystals of the following substances, and grow crystals of one kind: copper sulphate, salt, saltpetre, alum. When the crystals have grown to a reasonable size place them on a piece of blotting- or filter-paper to dry, and then put them into a specimen bottle.

EXPERIMENTS WITH CRYSTALS. 1. Powder some copper sulphate crystals. The copper sulphate is still in the crystalline state, although the crystals have been smashed up. Note that the colour of the finely powdered copper sulphate is much paler.

Weigh a porcelain crucible without a lid. Weigh it again with the powdered copper sulphate in it. Now heat carefully. Several striking changes take place. A vapour, like steam, comes off, and the crystals fall to pieces and become greyish-white in colour. Allow the crucible to cool and reweigh. Heat for five minutes

more and weigh again. When the weight is constant set out the following results:

	Grm.
Weight of crucible alone	
Weight of crucible + copper sulphate before heating . . .	
Weight of crucible + copper sulphate after heating . . .	
Weight of crucible + copper sulphate after further heating . .	
Weight of copper sulphate crystals used . .	
Loss in weight (due to the escape of water) .	

What is the loss in weight when 100 grm. of crystals are heated?

Before throwing the white copper sulphate away put the crucible on the palm of your hand and add two or three drops of water (adjust the tap to drip slowly). The blue colour is restored and great heat is liberated. Why? Chemists have concluded that copper sulphate cannot form crystals without 36·1 per cent. of water; drive this water away and the crystals lose their shape and their colour. Restore the water and the colour and the shape of the copper sulphate crystals return. In fact, crystals of copper sulphate are made up, as it were, of different kinds of bricks, copper sulphate bricks and water bricks, a definite number of each. Drive the water away and the crystal structure is no longer possible.

2. Find the percentage of water of crystallization in the following: alum crystals, soda crystals, salt (sodium chloride), potassium dichromate crystals.

Before leaving this chapter we may summarize the main ideas thus:

(1) Natural water is not always pure. Sometimes particles of sand, fibres, etc., can be seen in it. These can be removed by filtration, but the water is not pure until it has been distilled.

(2) Water is a solvent for many substances, but not for everything. Substances dissolved by water are said to be soluble in it; those which will not dissolve are said to be insoluble in it.

(3) Hot water will usually dissolve more than cold water. The solubility of a substance at a certain temperature is the number of grammes that will dissolve in 100 grm. of water at that temperature.

(4) When a hot saturated solution is cooled down to room temperature the excess of the solute appears as crystals. These have definite geometrical shapes bounded by plane faces. Crystals can be grown.

(5) Some crystals cannot form without water. When the water is driven out the crystal structure collapses. This water is called water of crystallization. The substance remaining is said to be anhydrous.

EXERCISES

1. Evaporate tap-water, distilled water, sea-water. Is there any dissolved matter?

2. Make a saturated solution of salt and find its density. (Use a specific gravity bottle, or measure out 25 c.c. of water and 25 c.c. of salt solution by means of a pipette, burette, or measuring bottle.)

3. Show by experiment how water and a solution of salt in water differ from each other.

4. Are Plaster of Paris, iron filings, and clay each soluble in water?

5. Find the percentage of soluble matter in a mixture of sand and borax.

6. Compare the behaviour of salt, copper sulphate crystals, soda crystals, and alum crystals when heated.

7. Grow crystals of copper sulphate, potassium dichromate, and alum.

8. Find the solubility of saltpetre, salt, and potassium dichromate at room temperature and at 100° C.

9. Calculate the solubility of a salt in water from the following data:

	Grm.
Weight of evaporating dish	75·3
,, ,, ,, + saturated solution	180·3
,, ,, ,, + salt left	115·9

10. Calculate the percentage of water crystallization in alum crystals from the following data:

	Grm.
Weight of crucible	7·87
,, ,, + alum crystals	9·14
,, ,, + alum (anhydrous)	8·56

CHAPTER XV

DISTILLATION OF WATER

WATER is sometimes solid (when it is called ice), sometimes a liquid, and sometimes a gas (when we lose sight of it entirely). When warmed in a pan ice changes to water and then passes into the air. When after a shower of rain the sun shines there is soon no trace of the rain on the road. The sun has chased the water away. Every day the sun is doing this on a grand scale, persuading the water of the seas and rivers and lakes to go on a wonderful voyage. It makes a pleasure trip of hundreds of miles—then it meets something cold and it returns to the liquid state as rain. Some of the rain sinks into the earth and works its way to a river, and so back to the sea. The trip can be represented as shown in Fig. 130.

The purest water that we find ready-made is rain-water, and whenever a new settlement is made the people first look round to see if water is available. There are certain regions which are rainless, and consequently nobody lives there. These regions are called deserts. In Egypt, India, and Australia large sums of money have been spent on the construction of irrigation works. When rain falls, or the rivers rise (through rain and snow falling elsewhere), the water can be stored up and used as it is required. Having water-pipes laid on in our houses, we find it difficult to realize the position of people living in country districts. For example, many farmers have to get their

water by boring a deep pit or well and pumping up all the water they require. Or they catch the rain-water that runs off the roofs of their houses in big rain-tubs. This water is only fit for washing clothes or watering the garden, for it has run over the roof and picked up some dirt. Large particles of dirt can be removed by

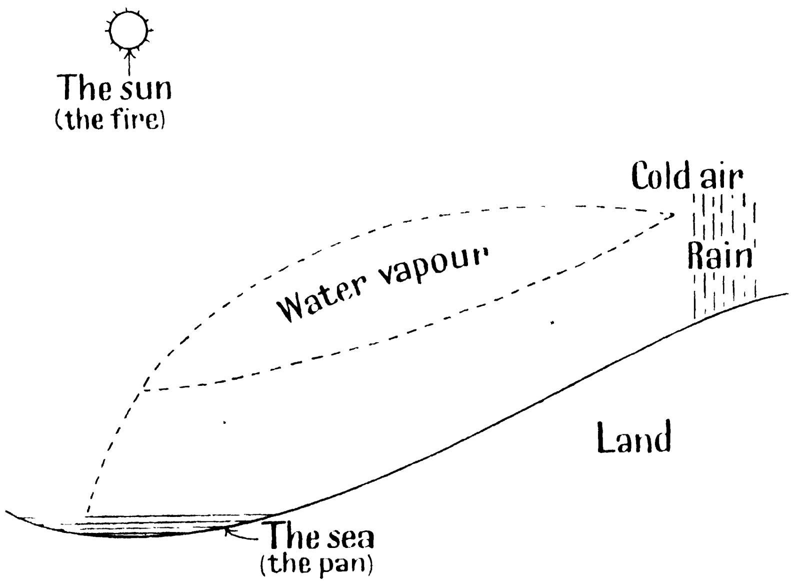

FIG. 130

pouring the water through a cloth or a filter-paper. This removes the insoluble impurities or suspended matter. Dissolved impurities are still present, however, in all natural water, although filtered rain-water and much river-water is safe enough to drink. Sea-water, stagnant water, and water that has been soiled by human beings or other animals would need purifying first. A quantity of very pure water can be obtained by distillation.

Put a kettleful of water on the fire. When steam

issues from the spout hold a plate in the vapour. A little pure water settles on the plate.

Fasten a piece of rubber on to the spout. You will soon see drops of water running out of the tube (Fig. 131).

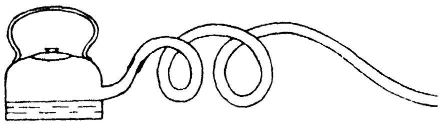

FIG. 131

When steam is changed back into the liquid state it is said to be condensed, and the water is called distilled water.

A plentiful supply of distilled water can be obtained by using the apparatus shown in Fig. 132.

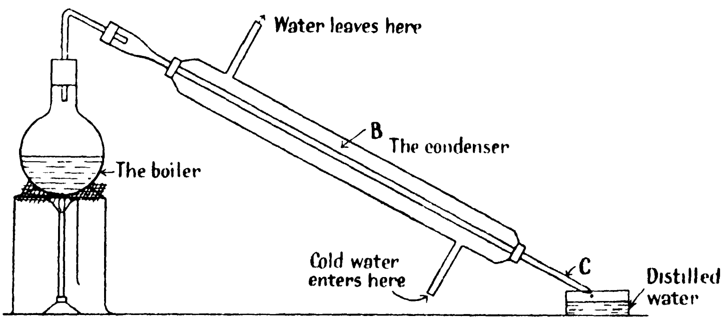

FIG. 132

A is the boiler, and it is on a tripod-stand. It is heated. A glass tube passes from the boiler to the condenser (B). Cold water runs through the latter, and it changes the steam passing through the inner tube to pure water, which runs out at C.

Taste some distilled water. It tastes flat and insipid, as the air previously dissolved in it has been expelled. Fishes would soon die in distilled water. At the Zoo

the water in the aquarium has to be changed frequently or air blown through the old water. All living things require air to keep them alive, but fish alone of all living creatures are able to get the air they require out of that dissolved in water.

CHAPTER XVI

FURTHER STUDY OF WATER

WATER is essential to all living things. We can live without air for only a minute or so, without water for two or three days, and without food for weeks if we are in the hands of a doctor. The water we drink is not the distilled water referred to in the last chapter; that is too expensive. We drink natural water and this term includes rain-water, river-water, well-water, etc. Sea-water is also natural water and it could be drunk if diluted. All natural water is really rain-water which has undergone changes after falling as rain. Part of this water sinks into the ground and later works its way to the surface in a spring—the beginning of a river; or it remains underground, dissolving matter out of the rocks; or it runs into sewers, and then into rivers, and finally into the sea. There is a great deal of well-water drunk, especially in country districts, and some authorities are in favour of using the great subterranean supplies which are believed to exist, instead of spending large sums of money in purchasing catchment areas and then conducting the water for miles to the towns. It is stated that the Bank of England saves £3000 a year by using its own wells instead of purchasing water from the Metropolitan Water Board.

Natural water cannot be absolutely pure—even rain-water which is caught as it falls is found to have picked up particles of dust, organisms, etc., from the air. Rain, in fact, condenses on dust particles, and in

addition washes the air. It has passed through hundreds of yards of air and has dissolved some of the gases of the atmosphere; spring-water may have travelled over long stretches of rocks and dissolved some of their constituents, besides various gases from the soil. River-water is sometimes turbid with the mud it has stirred up as it runs along, and it contains both

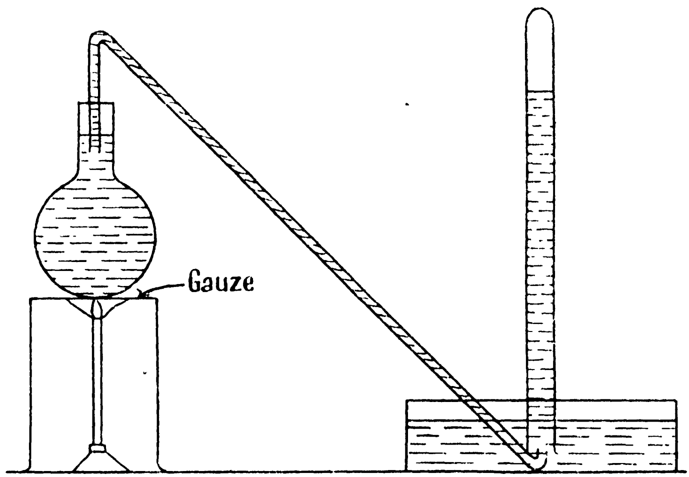

FIG. 133

dissolved and suspended matter. Finally rivers empty themselves into the sea and while some sea-water is fairly pure water other sea-water is so rich in salt as to be undrinkable.

EXPERIMENT. Examine some natural water.

(1) Filter the water. Is there any suspended matter in it?

(2) Boil some natural water in a flask. The flask should be quite full; also the delivery tube. Hold a test-tube full of water over the end of the delivery tube, as shown in Fig. 133. Slowly heat the flask. The gas

dissolved in the water will collect at the top of the test-tube.

(3) Evaporate some filtered natural water to dryness. If any solid particles are left behind they (with the gases found in (2)) are called the dissolved impurities.

(4) Does tap-water (a natural water) contain suspended or dissolved impurities? Some drinking-water is almost pure water, and often the solids present are not harmful, as they consist of salts which the body needs to keep it in good health.

Where people live in isolation they have to bore wells and draw up the water in buckets, or pump it up. Wells were very important in Old Testament times, and many of the struggles between the tribes were for possession of the wells. The Israelites were very grateful to those who dug them new wells—*e.g.*, Jacob's Well. A progressive municipality makes sure that it has a water supply to meet the natural growth of the town within the next 20 or 30 years. Manchester gets its main supply from Thirlmere in the Lake District, Birmingham and Liverpool from the heart of Wales, and Glasgow from Loch Lomond. Vast quantities of water are used in modern times. London consumes nearly 300,000,000 gallons daily. Its water is conveyed through 7000 miles of mains, ranging from 3 in. to 72 in. in diameter. Sixty per cent. of its water comes from the Thames. There is also a huge natural reservoir under London which is tapped by 2000 artesian wells, 400 to 600 ft. deep, from which 30,000,000 gallons of water are taken daily.

(5) We not only drink water but use large quantities for cleansing purposes. Originally water was used

alone; then various substances were dipped in water and rubbed over the body. These included clay, oatmeal, wood-ashes, and latterly soap. They all help to break up the layer of grease on our bodies, and when the grease is removed the dirt sticking to it goes too. Soap is made by boiling together fats and soda. Soap and glycerine are formed. In peace-time the soap is the main product, glycerine the by-product; but in time of war the glycerine is the more important as it is converted into explosives such as nitro-glycerine.

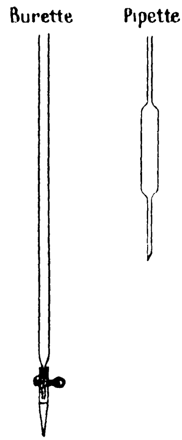

FIG. 134

EXPERIMENT. To see if natural water is hard.

(1) Mix some soap with water. Pour off the clear liquid.

(2) By means of a burette or pipette (Fig. 134) measure out, say, 10 or 25 c.c. of distilled water into a conical flask. Fill the burette with soap solution and run it into the distilled water, drop by drop, until a permanent froth or lather remains. The flask must be shaken after each portion of soap solution has been added. A permanent lather is defined as one that lasts two minutes.

(3) Repeat the last experiment with an equal amount of tap-water, river-water, spring-water, and sea-water, if available. Tabulate your results:

	No. of c.c. of soap solution
20 c.c. of distilled water required . . .	.
20 c.c. of tap-water required . . .	.
20 c.c. of river-water required . . .	.
20 c.c. of spring-water required . . .	.
20 c.c. of sea-water required . . .	.

Water which uses up much soap to make a lather is called 'hard water.' Distilled water, rain-water, and some river- and tap-waters are soft waters. Drinking-water need not be softened before use, but hard water which is going to be used in boilers must be softened or a hard, stony layer, consisting mainly of calcium carbonate, forms, and as this is a poor conductor of heat the coal bill is greatly increased.

Action of Metals on Water

Experiments. 1. Dip a knife-blade, a strip of copper, a platinum wire, and a silver coin in water. Have they any action on the water? It would be equally accurate to ask if the water has any action on the metals. It is more correct to say, do the metals and water act on each other or react with each other?

2. Watch very carefully while small pieces of sodium are put into some water in a wide dish. Sodium is an extraordinary metal. It is as soft as cheese and can readily be cut with a knife. The new surface of the metal is bright and silvery, but it soon gets covered over with a bluish-white film owing to the action of the oxygen in the air. Sodium is a very dangerous metal to use, and is kept under naphtha so that it will not get on fire. The pieces used in this experiment should be about the size of a lentil, and the person throwing them into the water should always stand back from the dish. It may not look very brave but it is a very wise precaution to take. The sodium is lighter than water, and goes racing about on the surface of the water. It becomes globular in shape, for so much heat is engendered that it melts and takes this shape. It hisses as it

rushes along, and finally disappears with a small explosion. You will notice that steam has arisen from the water on account of the heat. Repeat this experiment with the sodium placed on a piece of blotting-paper floating on the water.

3. Wrap a piece of sodium in some wire gauze and drop it into the water. The sodium sinks with the gauze and now bubbles of gas are seen to be coming off.

4. Repeat the last experiment, but have in readiness a gas-jar full of water, standing with its mouth under water. As soon as the gas begins to appear place the gas-jar over the bubbles and collect the gas (Fig. 135).

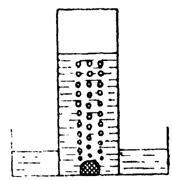

FIG. 135

Several pieces of sodium may have to be used to fill the jar with gas. Remember that it is far safer to use several small pieces of sodium than one big piece. Place the glass plate over the mouth of the jar and lift it out of the water. (See that the ground side of the plate is next to the ground rim of the jar.) Place the jar on the bench the right way up. Remove the plate and put a light to the gas. It explodes with a *pop*. The gas is hydrogen, although, being colourless, it might be mistaken for air. Examine the water into which the sodium has been dropped. Is it soapy to the touch? Does it taste of soap? (The naphtha will partly mask the taste.) Add to it pieces of red and blue litmus papers. How does water affect these papers? The water has been changed into a weak solution of sodium hydroxide. Evaporate the liquid to dryness and a small quantity of solid sodium hydroxide will be left. Compare this with pure sodium hydroxide.

Thus,

Water + sodium = sodium hydroxide + hydrogen.

Where does the hydrogen come from?

5. Repeat the last experiment using potassium instead of sodium. Here

Potassium + water = potassium hydroxide + hydrogen.

6. Repeat the experiment with calcium. This metal is the safest one to use, while potassium is the most dangerous. Calcium is not even kept under naphtha. Examine some old calcium. Why has it turned white? Has it any action on water? Even if you cannot see any action test the resulting liquid with litmus paper. What gas (if any) is given off? Describe the taste of the liquid. Similarly, test new calcium.

7. We have seen that there is no apparent reaction

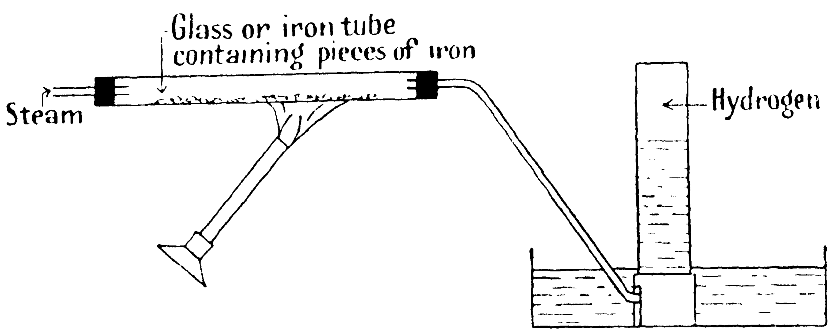

FIG. 136

when iron is placed in water. But we cannot say that there is no reaction between iron and water until we have tried hot water, or passed steam over red-hot iron. Suitable apparatus for investigating the action of steam on red-hot iron is shown in Fig. 136. Is any

hydrogen given off? What has happened to the iron? What happens to a piece of iron left out in damp air?

Before proceeding farther, tabulate the results of the action of metals and water on each other:

Metal used	Action
Sodium, Potassium	Attack water with violence. Hydrogen is liberated. A soapy liquid, sodium or potassium hydroxide, is left.
Calcium	Slow action on water. Hydrogen given off. Calcium hydroxide (limewater) is left.
Copper, gold, silver, mercury, etc.	No action on water.
Iron	No action unless the water and iron are left together for a long time. Steam and red-hot iron react with the formation of hydrogen and magnetic iron oxide.

The Action of a Current of Electricity on Water

A small current of electricity can be obtained from a single cell or accumulator, but to examine the action of electricity on water a battery of several accumulators should be employed. Join these in series and dip the free ends of the wires into some water in a pneumatic trough. Does anything happen? Now add a few drops of dilute sulphuric acid to the water. Does this make any difference? Wires of copper, silver, iron, etc. will allow a current of electricity to pass through them. These metals are called conductors. Sulphur, ebonite, vulcanite, rubber, etc., will not allow a current to pass: they are called insulators. Conducting wires are in-

sulated by being covered with rubber and cotton, and they are then safe to handle.

Water (made slightly acid) will not only allow a current to pass through it, but some change also takes place in the liquid, for bubbles rise from the ends of the wires. To study this action more carefully a voltameter should be used. Two forms of it are shown in Figs. 137 and 138.

In Fig. 137 the wires from the battery pass through apertures in the glass and end in small platinum plates

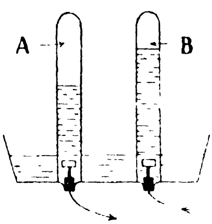

FIG. 137

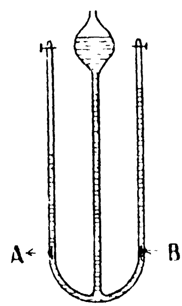

FIG. 138

called electrodes. The dish is partly filled with water acidulated with sulphuric acid, and after the two tubes have been filled with the same liquid they are put into position over the electrodes. In Fig. 138 the tubes A and B are closed by taps and instead of a dish to hold the water the latter is poured down the central tube until it rises to the tops of A and B, when the taps are closed. Switch on the current. Thousands of small bubbles rise from the electrodes and collect at the tops of the tubes. One tube fills nearly twice as fast as the other. The electrode in the former tube is called the 'cathode' and that in the latter the 'anode.' It has been found that the current leaves by the cathode and

enters the voltameter by the anode. The great scientist, Faraday, studied the action of currents on liquids very thoroughly and found that during electrolysis—the splitting up of a substance into its parts, or constituents, by means of an electric current—the amounts of liquids electrolysed were proportional to the times, and that during the electrolysis of water the volume of gas in the cathode tube was twice that in the anode tube. What are these two gases? In Fig. 137 the tubes can be removed from the dish. In Fig. 138 the gases can be passed into another tube by placing it over A or B and opening the tap, for the water forces the gas into the dry tube. Put a light to tube A: the gas burns with a *pop*. It is hydrogen. Put a light to the other tube: there is no *pop*, but the light burns more brightly, and the gas will even relight a glowing splinter with only a small spark on the end. This gas is oxygen. Advanced students of chemistry will learn later that the hydrogen and oxygen come from the water (in the proportions of 2 to 1) and not from the acid. Thus,

$$\text{Water} = \text{hydrogen} + \text{oxygen}.$$

Although water was not decomposed by electricity until the beginning of the nineteenth century, electrolysis has since been used very widely. Many substances can be decomposed by electricity—*e.g.*, a solution of brine to yield sodium hydroxide and chlorine, solutions of copper sulphate and silver salts in copper and silver plating, and fused bauxite and fused sodium chloride, to give aluminium and sodium respectively.

Substances like hydrogen, oxygen, iron, silver, and gold are called 'elements,' as they are believed to

contain only one kind of matter, or stuff. There are less than a hundred of these elements. Water, sulphuric acid, etc., are called 'compounds,' because they contain more than one kind of matter, combined together in definite proportions by weight (see Chapter XVIII, conclusions to Experiments 5 and 6). Air is a mixture of several kinds of matter. Some elements—*e.g.*, oxygen, silicon, and iron—are plentiful. It has been calculated that a man weighing 10 stones contains only about three shillingsworth of elements in his make-up, chiefly hydrogen, oxygen, carbon, phosphorus, iron, and calcium.

Summary. (1) Rain-, river-, spring-, well-, and sea-water are called natural waters to distinguish them from artificial or distilled water.

(2) Natural waters contain:

(*a*) Suspended impurities, removed by filtration.

(*b*) Dissolved impurities: gases and solids, which may be removed by distillation.

(3) The dissolved impurities often make the water hard—*i.e.*, so that it will not lather easily and therefore more soap has to be used.

(4) Clay, oatmeal, wood-ashes, and soap are used for cleansing purposes. Soap is made from fats and soda, and glycerine is a by-product. A soap solution is used to measure the hardness of a sample of water.

(5) Many metals act on water.

(*a*) Quickly. *E.g.*, sodium and potassium.

(*b*) Slowly. *E.g.*, calcium. A hydroxide and hydrogen are produced in this and the previous case.

(*c*) No action. *E.g.*, copper, silver, gold.

(*d*) Iron. Rusts in moist air. When the metal is red hot and the water is in the form of steam the products are hydrogen and oxide of iron.

(6) Electrolysis is the phenomenon of the splitting up of compounds into their constituents by electricity. Where the electricity enters the voltameter is called the 'anode,' and where it leaves the 'cathode.' Metals and hydrogen are always deposited on the cathode, and oxygen on the anode. Water can be split up into hydrogen and oxygen in the ratio of 2 to 1 by volume. By weight, one-ninth of all the water in the universe is hydrogen and eight-ninths are oxygen.

EXERCISES

1. Find by experiment the volume of air dissolved in 100 c.c. of tap-water.
2. Is the water in the laboratory hard or soft? Compare it with equal amounts of distilled water and limewater.
3. How is the hardness of water affected by adding separately sodium sulphate, magnesium sulphate, calcium sulphate, and copper sulphate to distilled water. Use 25 c.c. of each of the solutions provided.
4. Examine a voltameter. What two gases are collected when a solution of sodium hydroxide is electrolysed?

CHAPTER XVII

THE ATMOSPHERE

WINDS are due to the rapid motion of the atmosphere, the nature of which covering has been discovered only in comparatively modern times, and even now there is still great uncertainty as to the nature of the atmosphere ten or fifteen miles high, in which Professor Piccard and others are now carrying out pioneer work. Air has weight. Weigh an empty football; then pump it up and weigh it again.

Air, like most other substances, expands when heated and contracts when cooled. It can be liquefied and solidified.

But of what is the air composed? The answer to this question was not discovered all at once but, like most other solutions to nature's puzzles, bit by bit and over a long period of years. These are some of the discoveries that man has made about the atmosphere:

(1) The sun evaporates some of the water of the earth: a puddle is soon dried up if the sun shines brightly for a few hours. Therefore there must be a constant backward and forward movement of the water—first it evaporates, then forms clouds, and later falls as rain. But the atmosphere always contains some water.

(2) It has long been known that rooms containing a large number of people become stuffy, and that certain caves were known as 'caves of death.' The winds blow and disperse this bad air, but the gases that make air bad are still somewhere in the atmosphere.

(3) People have often been imprisoned in small rooms without ventilation and many have died of suffocation. In 1756 Surajah Dowlah crowded 146 persons into the Black Hole of Calcutta—a room barely twenty feet square and containing only two small barred windows. Only twenty-three survived until next morning, the others dying from lack of oxygen, heat stroke, or stampede. When slaves were being carried from Africa to America they were often packed so tightly in the hold that many died before they crossed the Atlantic. Air must be renewed if life in it is to continue. Part of the air, at least, is necessary for life. What this part is was not known until the eighteenth century.

(4) During the latter half of the eighteenth century three great chemists discovered what this 'something' was, and how it took part in respiration, burning, etc. We must remember that there were no telephones, telegraphs, or other means of rapid transmission of knowledge, and in the early history of science several persons appeared as 'discoverers' of the same thing, sometimes at intervals of years. The discovery of oxygen was one such instance.

Scheele (1742–86) was a Swedish apothecary, and he is described as one of the greatest experimental chemists of all time. He obtained oxygen from different substances, and it is quite safe to repeat his experiments. He called his oxygen 'fire air' and 'vital air.'

Experiments. 1. Heat red oxide of mercury in a test-tube. Test the gas given off with a glowing splint, and examine the upper portion of the tube (Fig. 139).

2. Heat manganese dioxide alone or with strong

sulphuric acid. Be careful when you do the second part of this experiment.

3. Heat saltpetre in a test-tube.

In every case the same gas comes off, and when it comes into contact with a glowing splint the latter is relighted. This is the usual way of recognizing oxygen when it is present in large quantities.

Priestley (1733–1804) independently discovered oxygen a little later. The Bunsen burner had not yet

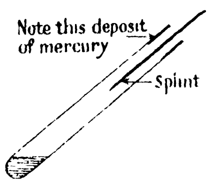

FIG. 139

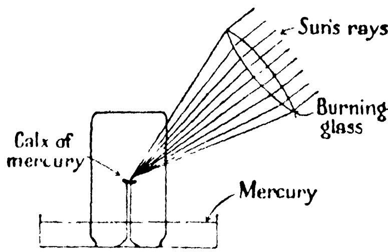

FIG. 140

been invented, so whenever great heat was required a large burning-glass was used. Fig. 140 shows Priestley's apparatus. He heated red calx of mercury—*i.e.*, red oxide of mercury—by means of a burning glass 12 in. in diameter. He easily succeeded in obtaining both mercury and an 'air' which did not dissolve in water, but which made a candle burn more brightly in it. Priestley told Lavoisier (1743–94) of his discovery. Lavoisier himself had been carrying out experiments on the burning of metals in air, and had found that in every case the 'calx,' or 'rust,' was heavier than the metal. Lavoisier concluded that the metal had removed something from the atmosphere and had combined with it. He knew that a substance when burned in air enclosed in a bell-jar over water did not combine

with all the air, for about four-fifths of the air was always left afterwards. This residual air would not support combustion and was fatal to the life of animals. Lavoisier therefore thought that air consisted of two gases:

(1) Active air, which is concerned in combustion and breathing.
(2) Inactive air, which takes no part in these changes.

On hearing of Priestley's discovery he jumped to the conclusion that Priestley's gas was his 'active air.' We now know definitely that it was so, and the gas was named oxygen. When a metal is heated in air so as to form a calx or a rust there is always an increase in weight because the metal has gained some oxygen; it has combined with it.

Copper + oxygen = copper calx, or copper oxide.
Mercury + oxygen = mercury calx, or oxide of mercury.

Our present knowledge enables us to say that the atmosphere contains

(1) Water-vapour.
(2) Gases produced by breathing, or respiration, and by burning substances such as coal and wood.
(3) Floating matter, such as dust, microbes, etc.
(4) Active air, or oxygen.
(5) Inactive air, or nitrogen.

Water-vapour. We know that this is present in the air because rain falls from the atmosphere, dew is

deposited, and fogs and mists appear. On a hot summer's day, when the sky is cloudless, it may be difficult to believe that it is there. But if some air is blown through a glass tube containing concentrated sulphuric acid, the water is retained by the acid, which increases in weight. Also, anhydrous copper sulphate over which air is blown becomes slightly blue.

Carbon Dioxide. We shall see later that the two gases produced during respiration are water-vapour and carbon dioxide. Breathe on to a cold surface: water is deposited from your breath. Breathe through a glass tube into some limewater. The carbon dioxide in the breath turns it white. It will go white when exposed to the air for a long time.

The Floating Matter in the Air. Take a funnel, put a piece of cotton-wool in it, and draw air through by means of an air-pump (Fig. 141).

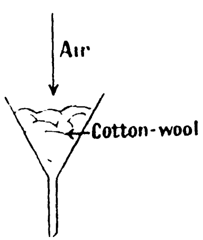

FIG. 141

The cotton-wool may become black, depending on the place where you live. The curtains in your houses are good indicators of the cleanliness of the air in your neighbourhood. The nose is lined with hairs so as to give the air breathed in a preliminary cleaning and warming before it enters the lungs. Microbes of disease, ferments, etc., are present in the atmosphere, although some microbes are readily killed by sunlight. The lactic acid ferment falls into milk and turns it sour; the mycoderma aceti falls into wine and the juices of fruits and turns them sour.

Oxygen and Nitrogen. These two gases together make up about 99 per cent. of the atmosphere, and they are present in the proportion, by volume, of one

part of oxygen to four parts of nitrogen. The following experiment will prove this statement:

A bell-jar is placed in a pneumatic trough containing water. The rubber stopper is removed from the jar and the water rises in it until the level is the same inside as outside. A crucible lid is put on a large cork which floats on the water inside the bell-jar (Fig. 142). In the lid is placed a small piece of phosphorus, which is ignited by a red-hot wire. The rubber bung is firmly pressed into the neck of the bell-jar so that air can neither enter nor escape. The bell-jar becomes full of white fumes. Just as mercury changes to oxide of mercury when it combines with oxygen, so phosphorus becomes oxide of phosphorus. In a short time the phosphorus ceases to burn and the bell-jar becomes clear again. The level of the water in the jar is higher than at the beginning of the experiment, for as oxygen is used up water from the pneumatic trough enters to take its place. A paper scale, arranged alongside the bell-jar, will show that water has entered about one-fifth of the height.

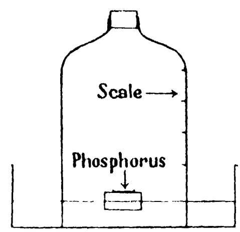

FIG. 142

Remove the rubber bung, put a light into the jar, and you will find that the remaining gas, called by Lavoisier 'inactive air,' does not keep the light burning. This gas is now called 'nitrogen.'

You may, for the present, regard the air as being nearly four-fifths nitrogen, just over one-fifth oxygen, a little carbon dioxide, and a small variable percentage of water-vapour.

The great bulk of the oxygen and nitrogen in the air is free, but lightning converts a little of them into

oxides of nitrogen. These dissolve in rain and give acid solutions containing nitrogen. (Our modern method of preparing nitric acid from the atmosphere is based on this idea.) There are estimated to be 16,000,000 thunderstorms a year throughout the world, or 44,000 a day. Through the action of these the soil is greatly enriched in nitrogen.

The Rusting of Iron

Scientists have been trying for a long time to prevent the rusting of iron, and in recent years stainless and rustless steel have been produced. A non-rust iron will save millions of pounds, as ironwork will not have to be replaced so frequently. Paint keeps air from the surface and so prevents rusting. The following experiments tell us all that is really known about the rusting of iron.

Take four test-tubes, (i), (ii), (iii), (iv). In each tube place a bright nail (Fig. 143).

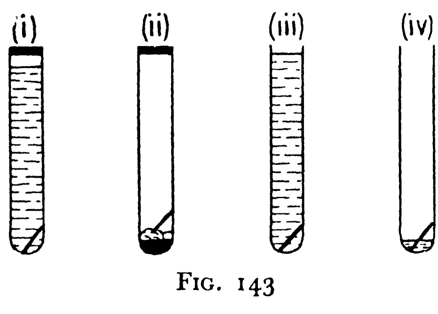

Fig. 143

(i) is nearly filled with distilled water (which is free from air) and some vaseline or wax is used to seal the tube so that air cannot enter the water and reach the nail. Here the nail is in contact with water but not with air. Result: No rusting.

(ii) is tightly stoppered with a rubber bung. At the bottom of the tube is some freshly prepared quicklime to dry the air in the tube. It is covered lightly with glass-wool or cotton-wool, or a pad of paper, so that the lime and the nail are kept away from each other. The nail is now in contact with dry air but no water. Result: No rusting.

(iii) is full of tap-water, and this contains a little air dissolved in it. The nail is in contact with much water and a little air. Result: Rusting takes place.

(iv) contains a few drops of water, so that there is much air and a little water. Result: Rusting takes place.

Scientists have concluded that for rusting to take place damp air (which contains water-vapour, carbon dioxide, oxygen, and nitrogen) is necessary.

Rust is composed of iron, oxygen, and water, and from it pure iron can again be obtained.

EXERCISES

1. Devise an experiment to show that air has weight.
2. Heat lead, copper, and magnesium separately in the air and see if they change in appearance, weight, etc. Suggest names for the products.
3. Leave (1) some powdered calcium chloride and (2) a little strong sulphuric acid exposed to the air for a few days. Describe and explain what happens in each case.
4. Take a tube about 18 in. long and sealed at one end. Rinse it out with water, and then dust finely divided iron filings on the inside. Invert the tube with its mouth under water in a trough. Leave it to rust. How high does the water rise in the tube. Why?
5. Carry out or observe experiments to show that damp air is necessary for rusting to take place.

CHAPTER XVIII

OXYGEN

Occurrence. Oxygen is the most plentiful substance in the world.

(i) It forms one-fifth of the atmosphere, by volume.
(ii) 8 out of every 9 lb. of water are oxygen.
(iii) 50 per cent. of the earth's crust is oxygen.
(iv) It is present in every living thing, plant and animal.

Preparation in the Laboratory. Although it is so plentiful both in the air and in water, it is most easily prepared in the laboratory by heating certain substances which are known to contain it.

(1) *Oxides.* These all contain the gas, but some oxides will not part with their oxygen however strongly they are heated. Lime is calcium oxide; sand is mainly silicon dioxide. Will either give up oxygen when heated? Mercuric oxide will give up its oxygen when heated, and this is how Scheele and Priestley first prepared the gas. Repeat their experiment (see Fig. 139). Use a test-tube holder.

Keep the test-tube moving in the flame, and from time to time put a glowing splint into the mouth. It will relight when the oxygen is coming off. Examine the test-tube near the mouth. On the cold part of the tube a greyish deposit appears on the inside of the tube (Fig. 139). Scrape it together with a splint or a piece of paper. It is mercury, and you may get

enough to form a small bead. The experiment shows us that

Mercuric oxide = mercury + oxygen.

(2) Repeat two other of Scheele's experiments to see if you can get oxygen by heating saltpetre and manganese dioxide.

(3) Heat potassium chlorate, the substance used in making potash pellets. Oxygen will come off and a white solid, potassium chloride, will be left:

Potassium chlorate = potassium chloride + oxygen.

Conclusion. Oxygen may be prepared in the laboratory by heating certain oxides, saltpetre, or potassium chlorate.

An important discovery was then made, namely, that a little manganese dioxide when mixed with the potassium chlorate in some mysterious way (not yet satisfactorily explained) caused the oxygen to come off at a lower temperature, or, if the same Bunsen flame were used, resulted in the gas coming off more rapidly than before. The manganese dioxide is not changed during the action, all the oxygen coming from the potassium chlorate. A substance which helps in a chemical change without being itself changed is called a 'catalyst.' In this particular action the manganese dioxide acts as a catalyst.

The apparatus illustrated in Fig. 144 is suitable for preparing oxygen in the laboratory from a mixture of potassium chlorate and manganese dioxide. Keep the Bunsen moving to ensure uniform heating of the tube. The delivery tube passes under a beehive shelf. The gas-jar is full of water, and, since water and oxygen cannot occupy the same space at the same time, as

gas enters the jar the water is expelled. When the jar is full of oxygen replace the glass plate, ground glass to ground glass, and lift the jar out of the trough. Collect

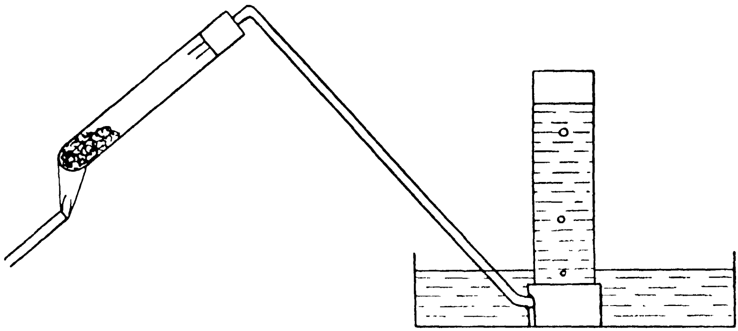

FIG. 144

several jars of oxygen. This method of collecting a gas is known as 'collection over water,' and may be used for collecting any gas which is insoluble, or only slightly soluble, in water. When the oxygen stops coming off remove the delivery tube from the pneumatic trough or remove the stopper from the test-tube. This will prevent the water from running back into the hot tube.

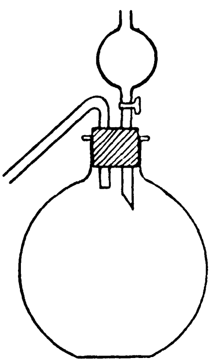

FIG. 145

Another way of getting oxygen is to place some sodium peroxide in a flask and by means of a dropping-funnel, controlled by a tap, slowly drop water on to it. Collect the gas in the same way as before (Fig. 145).

Sodium peroxide + water = sodium hydroxide + oxygen.

Later you will learn how oxygen is obtained on a very large scale from air and water.

Physical Properties. (1) It is colourless, odourless, and tasteless.

(2) It is slightly heavier than air and consequently nitrogen, the other important constituent in the atmosphere, is slightly lighter than air.

(3) It is slightly soluble in water. (In fact, fishes live on the oxygen dissolved in water. They cannot live in distilled water and even tap-water or any other form of natural water has to be aerated in order that they may live in it. Sea-water, etc., is aerated by the winds.) The air dissolved in water is twice as rich in oxygen as the air we breathe, as water dissolves oxygen more readily than nitrogen.

(4) Oxygen can be liquefied and solidified.

Chemical Properties. Oxygen is a very active substance, by which we mean that it readily acts on other substances, changing them into entirely new compounds.

Some substances are changed immediately on coming into contact with oxygen—*e.g.*, metals like sodium and potassium. When freshly cut they are silvery in appearance and really look like metals, but the oxygen of the air, and still more rapidly pure oxygen, makes the bright surface tarnish, changing the part exposed into an oxide, sodium and potassium oxides respectively. Other substances, such as copper and magnesium, are changed to their oxides only when heated in air or oxygen.

Sodium + oxygen = sodium oxide.

Potassium + oxygen = potassium oxide.

Magnesium + oxygen = magnesium oxide (magnesia).

Copper + oxygen = copper oxide.

These metals are said to be 'oxidized' by the oxygen, and as they, and many other substances, burn in

oxygen, the gas is said to be a supporter of combustion. Wood, paper, etc., are 'combustible' in air or oxygen.

Note. If oxygen acts on a substance when it is cold it will act on it more readily when it is heated.

Carry out the following experiments with magnesium, calcium, and sodium, which are metals, and carbon, red phosphorus, and sulphur, which are non-metals. Use a separate gas-jar for each substance, and heat them in a deflagrating spoon (Fig. 146). First adjust the brass plate so that the spoon will not touch the bottom of the jar. Light the substance in the Bunsen flame and place the spoon in the jar. Some things—*e.g.*, sodium and magnesium—burn violently, so great care must be taken. When the reaction is over remove the spoon and pour a little water into the jar. Shake up. (In the case of the magnesium experiment it will be better to pour the white liquid into an evaporating dish and boil before you do the next part of the experiment.) Drop into each jar two pieces of litmus paper, one red and one blue. What happens? Tabulate thus:

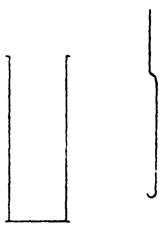

FIG. 146

Substance heated		What is formed? Appearance, Smell, etc.	Action on Litmus
Metals	Sodium		Red litmus turned blue.
	Magnesium		
	Calcium		
Non-metals	Phosphorus		Blue litmus turned red.
	Sulphur		
	Carbon		

Conclusions. (1) Substances heated in oxygen are either

(*a*) unchanged—*e.g.*, gold, silver, platinum;
(*b*) changed.

(2) Substances which are changed become oxides.
(3) These oxides can be divided into two classes:

(*a*) *Oxides of Metals.* These dissolve in water and form liquids which turn red litmus blue. These solutions are said to be alkaline. The three alkalis discussed are sodium hydroxide, magnesium hydroxide, and calcium hydroxide.
(*b*) *Oxides of Non-metals.* These dissolve in water to give acid solutions. The three acids obtained in the last experiment are called phosphoric acid, sulphurous acid, and carbonic acid respectively.

EXERCISES

1. See if you can obtain oxygen by heating the following oxides: manganese dioxide, lead monoxide, lead dioxide, red lead, ferric oxide.
2. Prepare oxygen by heating in a test-tube (*a*) potassium chlorate alone, (*b*) potassium chlorate and a little manganese dioxide.
3. Prepare several jars of oxygen and burn sulphur, carbon, red phosphorus (beware), magnesium (beware) in separate jars. Add a little water, shake up, and test the resulting liquids with litmus papers.
4. Burn a small piece of zinc in oxygen, or heat it strongly in air. See if the white powder will dissolve in water (cold or boiling?).
5. Weigh a piece of magnesium ribbon and heat it in a closed

crucible until no further change takes place. Lift the lid from time to time to allow a little fresh air to enter. Calculate the weight of oxygen which combines with 100 grm. of magnesium. What conclusion do you draw from your result?

6. Find the percentage loss in weight when potassium chlorate is heated. What conclusion do you draw from your answer?

CHAPTER XIX

ACIDS, BASES, AND SALTS

Acids

Many hundreds of different acids are known, and some of them are in everyday use. Some are solid, some liquid, and some gaseous at the temperature of the room.

Solid acids include tartaric acid (present in health salts), citric acid (present in lemons and oranges), and boric, or boracic, acid (an antiseptic).

Liquid acids include oil of vitriol (sulphuric acid), acetic acid (present in vinegar), and aqua fortis (nitric acid).

Gaseous acids include hydrogen chloride (a solution of this is on the bench under the name of hydrochloric acid).

The two strongest acids known are hydrochloric acid and nitric acid, and a good third is sulphuric acid. The latter is the best to experiment with first. It is oily-looking—it is also called oil of vitriol—and is nearly twice as heavy as water (volume for volume). It is very dangerous to use.

Experiments. 1. Powder some sugar, or alternatively make a very strong aqueous solution of sugar. Very carefully pour the strong acid into the solution, stirring all the time. The liquid goes brown, then black, and finally a large mass of shining black material fills the vessel and overflows. There is a smell of burnt sugar. The black mass is almost pure carbon, and the

sulphuric acid has so great an avidity or thirst for water that it has extracted it from the sugar. You cannot, however, make sugar by shaking together carbon and water. What the sulphuric acid has done to the sugar it will do to many other substances, such as your skin and clothing. If any gets on your hand, bench, clothing, etc., wash it away immediately with plenty of water.

It is very dangerous and even fatal to taste this acid. The dilute acid on the bench is obtained by adding slowly one volume of the concentrated acid to 5 volumes of water. So much heat is given out during the process that it is better to do the mixing on two successive days. Take a test-tube three-quarters full of water. Add the strong acid to it, a few drops only. (*Note*. The acid is always added to the water.) Notice how the heavy acid sinks to the bottom of the water. This liquid is still too strong to taste, so pour a few drops into another test-tube containing water. Shake up and taste.

2. Put a piece of zinc into a test-tube and add some dilute sulphuric acid (this is the 'dilute' acid on the bench). Do the two substances react? Is there any heat generated? Does any bubbling occur? If so a gas is coming off. Hold your thumb over the mouth of the test-tube so as to cause the gas to accumulate. Then put a light to it. What is the gas? Repeat the experiment using marble, limestone, or chalk instead of zinc.

3. What is the action of the acid on red and blue litmus paper?

4. Dip a wooden splint and a strip of cloth into the strong acid.

Hydrochloric Acid. Repeat the above experiments

with concentrated hydrochloric acid, omitting Experiment 1.

Nitric Acid. Repeat the above experiments with concentrated nitric acid, omitting Experiment 1 and using copper instead of zinc in Experiment 2.

Conclusions. You have studied some of the properties of the three strongest acids. If you use weaker acids you will not find their properties so pronounced. For example, tartaric acid is a weak acid, and you can safely suck a crystal. You must on no account taste a drop of the three strong acids mentioned above. The chief properties of acids are that they

(1) Have a sour taste.

(2) Turn blue litmus red.

(3) Corrode, or eat away, certain metals, such as iron and zinc. Copper is attacked by nitric acid but not by hydrochloric. Gold and platinum are not attacked by any single acid.

(4) Act on certain rocks—*e.g.*, marble, limestone, chalk.

Many acids do not begin to act until some water has been added. *E.g.*, tartaric acid and carbonate of soda in health salts, baking-powder, etc., do not change for years if kept dry.

Alkalis

The two strongest alkalis in common use are solutions of sodium and potassium hydroxides. Limewater is a weak alkali. Do the following experiments, first with sodium hydroxide solution and then with potassium hydroxide solution:

(1) Taste a very weak solution.

(2) Discover its action on litmus.

(3) Rub a little on the hands and then wash it off.

(4) Determine if they have any action on metals, say, on zinc.

SALTS

We have seen that acids turn blue litmus red and that alkalis turn red litmus blue. What happens when two solutions, one acid and the other alkaline, are mixed?

EXPERIMENT. Fill a burette with dilute hydrochloric acid. Place a conical flask, with some solution of sodium hydroxide in it, under the burette, and add a few drops of litmus solution to act as an indicator. Run the acid drop by drop into the flask and after each addition of acid shake the flask so as to get the contents thoroughly mixed. In time the liquid will be neither red nor blue, but purple, and another drop or so of acid will turn the liquid distinctly red. When the liquid is purple it is said to be neutral.

Evaporate some of this liquid to dryness. The litmus will colour the residue. Taste it. It has the taste of, and actually is, common salt. Its chemical name is sodium chloride. (Actually household salt contains a small portion of some other compounds besides sodium chloride.)

If you know the proportions in which the two solutions have been mixed to neutralize each other you can repeat the experiment without the litmus, and you will then obtain a white crystalline solid which is like salt in appearance. Vary the experiment, using different alkalis and acids. The substance left when the neutral liquid is evaporated to dryness is called a salt.

Tabulate your results.

Acid	Alkali	Salt
Hydrochloric . .	Sodium hydroxide Potassium hydroxide	Sodium chloride
Sulphuric . .	Sodium hydroxide Potassium hydroxide	
Nitric . . .	Sodium hydroxide Potassium hydroxide	

An alkali is the aqueous solution obtained by dissolving a metallic oxide in water, but many metallic oxides are only very slightly soluble in water. How can we make salts from these?

EXPERIMENT. Put some dilute sulphuric acid in an evaporating dish and heat. Gradually add black copper oxide, putting in a little more as each portion dissolves. At length no more will dissolve. (How do you know?) See if the solution is neutral. The blue solution cannot be sulphuric acid. Why not? Filter to get rid of any excess of copper oxide. Evaporate the solution down a little and allow it to cool. The blue crystals which form are copper sulphate crystals.

Thus a metallic oxide which will not dissolve in water has both dissolved in sulphuric acid and neutralized it. Other metallic oxides behave in the same way. They are generally called bases, and bases, acids, and salts can be defined in terms of each other: *Acids* neutralize (or are neutralized by) *bases* to form *salts*.

The best-known salt is called common salt. It is mainly sodium chloride, and can be prepared in a pure state by neutralizing sodium hydroxide with hydrochloric acid. Other well-known salts are borax (sodium borate), saltpetre (potassium nitrate), Chili

saltpetre (sodium nitrate), Glauber's salt (sodium sulphate), Plaster of Paris (calcium sulphate), soda crystals (sodium carbonate), and chalk, limestone, and marble (mainly calcium carbonate).

EXERCISES

1. Examine the properties of several acids as explained in this chapter.

2. Do the same with sodium, potassium, calcium, and magnesium hydroxides.

3. Make copper sulphate crystals from copper oxide and sulphuric acid. If 5 grm. of copper oxide are used, what weight of crystals is obtained?

4. What weights of salts are obtained when 5 grm. of calcium oxide and 5 grm. of zinc oxide, together with the requisite amounts of sulphuric acid, are used?

5. Repeat Exercises 3 and 4, using hydrochloric acid instead of sulphuric acid.

CHAPTER XX

HYDROGEN

HYDROGEN was discovered by Cavendish in 1766. He prepared it by acting on zinc with dilute sulphuric or hydrochloric acid, and called it inflammable air. It was named hydrogen (Greek, water producer) by Lavoisier. In 1802 water was decomposed by electricity, and hydrogen and oxygen obtained.

Occurrence. (1) One ninth, by weight, of all water is hydrogen.

(2) It is present in all living things, in coal, which has been produced from plants, and in oil, fats, acids, hydroxides, etc.

(3) It is very plentiful in the sun and other heavenly bodies.

Preparation. (1) Act on metals such as zinc, iron, magnesium, etc., with dilute hydrochloric or sulphuric acid.

(2) Act on water with small pieces of sodium, potassium, calcium, etc.

(3) On the large scale it is prepared by electrolysing water and certain aqueous solutions (such as brine, when it is a by-product), and by passing steam over red-hot iron.

Carry out method (1) in the laboratory. Fit up the following apparatus (Fig. 147).

The conical flask is fitted with a two-holed stopper. Through one hole passes a thistle funnel and through the other a delivery tube. The gas is collected over

water. Zinc is put into the flask and water added to cover it. See that the thistle funnel is in position—*i.e.*, the end is just under the water. It serves two purposes: the acid is poured down it, and it acts as a safety valve, for if the gas cannot get away quickly enough it forces the liquid in the flask some way up the tube and then

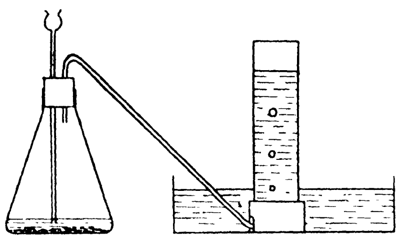

FIG. 147

gradually escapes. If the end of the funnel is above the liquid in the flask the gas escapes by that exit.

Add strong sulphuric or hydrochloric acid, which, with the water already in the flask, makes dilute acid. There is an effervescence, or fizzing, which shows that an action is taking place and that a gas (hydrogen) is coming off. The flask gets hot, showing that a chemical action is taking place. In the gas-jar bubbles of gas rise through the water and force it out. When the jar is full cover the mouth with a glass plate, remove it from the trough, and put it on the bench upside-down. Fill two or three other jars. Since the first gas will not be pure hydrogen as it has mixed with the air in the flask, a little gas may be allowed to escape before you begin to collect. Do the following experiments.

EXPERIMENTS. 1. Hold a jar upside-down, remove the plate, and put a light to the mouth of the jar. The gas burns; it is combustible. The explosion puts the light out, but the gas burns for a few seconds, the flame

rising slowly up the jar. Push the lighted splint through the flame into the top portion of the jar; it goes out. Though hydrogen burns, or is combustible, in air, it will not support combustion. There is a film of water on the inside of the jar (Fig. 148).

Hydrogen + oxygen = hydrogen monoxide (water).

2. Hold a jar of hydrogen right way up and put a jar of air above it (Fig. 149). Remove the two glass

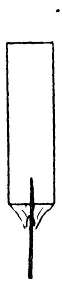

FIG. 148

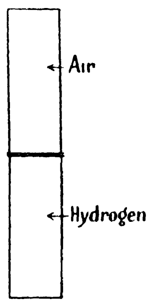

FIG. 149

FIG. 150

plates and leave the jars together, mouth to mouth, for ten seconds. Then put the plates back. Test the gases in the two jars with a light. In both cases there is a *pop*, showing that some hydrogen has quickly shot up into the top jar on account of its extreme lightness (it is the lightest substance known).

3. Place the third jar on the bench right way up and apply a light to the gas (Fig. 150). This time there is a single loud *pop*, for as the gas is so light it quickly rises into the air, forms an explosive mixture with it, and explodes violently when a light is put to it. Again there is a film of water on the inside of the jar.

Physical Properties. (1) It is colourless, odourless, tasteless.

(2) It is the lightest gas known.

(3) It dissolves so slightly in water that it can be collected over it.

(4) It can be liquefied and solidified, though not so easily as oxygen.

Chemical Properties. (1) It burns in air or oxygen, forming water, but it will not support combustion. During the War helium was mixed with the hydrogen used in airships to prevent the gas from catching fire.

(2) You will learn later that it combines with many other substances—*e.g.*, with chlorine to form hydrogen

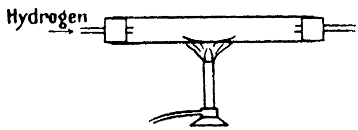

FIG. 151

chloride, with nitrogen to form ammonia, and with carbon to form acetylene, marsh gas, etc.

(3) Owing to its great affinity, or longing, for oxygen it will take it out of various oxides if they are heated in a current of the gas. Generally the oxide—*e.g.*, copper oxide or lead oxide—is put into a porcelain boat placed in a wide horizontal tube, and the hydrogen is passed over while the oxide is being heated (Fig. 151). The hydrogen is said to 'reduce' the metallic oxide, and the metal—*e.g.*, copper or lead—is left.

The Contents of the Hydrogen Flask. When the liquid in the flask has stopped effervescing filter it. Evaporate a portion of the filtrate to smaller bulk and try to get crystals. In the third column of the table given at the top of the next page write down the name of the crystal or salt that you would expect to obtain.

Acid	Metal	Residue
Sulphuric . .	Zinc Magnesium Iron	Zinc sulphate
Hydrochloric . .	Zinc Magnesium Iron	

The substance left behind after an experiment has been performed is often valuable—*e.g.*, the zinc sulphate referred to above is used for making 'drops' for the eye, as an antiseptic and a preservative for wood and skins, and in calico-printing. After the making of soap from fats and soda a liquid remains which contains glycerine. The scientist is constantly trying to find uses for rubbish, remnants, waste, and residues.

EXERCISES

1. See if you can get any hydrogen from zinc and sulphuric acid. If not, try the effect of adding a few drops of copper sulphate solution.
2. Can you get hydrogen from magnesium and nitric acid or from copper and nitric acid?
3. Get hydrogen by electrolysing water containing a few drops of sulphuric acid or sodium hydroxide.
4. Prepare three or four jars of hydrogen as described in the text and carry out experiments with them.
5. Examine the residue from the hydrogen experiment. Prepare and name the crystals. Dry them on blotting-paper and put into a specimen bottle.

CHAPTER XXI

CARBON AND CARBON DIOXIDE

Occurrence. Carbon, like oxygen and hydrogen, occurs plentifully in nature.

(1) It is present in all living things, plant and animal.

(2) It is present in varying amounts in coal:

Lignite . . .	50 per cent.
Bitumen . .	80 ,, ,,
Cannel . . .	83 ,, ,,
Anthracite . .	93 ,, ,,

Oils and fats also contain this element.

(3) Many rocks contain it: marble, limestone, and chalk, which are forms of calcium carbonate; dolomite, which is mainly magnesium carbonate; soils, etc. Carbon also occurs in the free state as diamond, graphite, and amorphous carbon.

Forms of Carbon

Diamond. Diamonds have been prized as gems from very early times. They are found in South Africa, Brazil, Australia, etc. The largest diamond ever found weighed a pound and a quarter.

Diamond is the hardest substance known and will scratch every other substance. Diamond will cut diamond, and inferior ones and small ones are used for polishing other diamonds and, in glass cutters, for cutting glass. Boring implements are now faced with diamonds and used for boring through hard mountain

rocks. Diamond has a specific gravity of 3·5. The heat of a good Bunsen flame is sufficient to spoil a diamond, changing it to graphite; but the process of converting graphite to diamond cannot yet be performed. Both diamond and graphite exist in the form of crystals, but their shapes and their properties are different.

Graphite. This form will mark paper, and it received its name on that account (Greek *grapho*, I write). It is also named plumbago, or blacklead, because it was thought to be lead (*plumbum*), which also marks paper.

It occurs naturally in Cumberland, Bohemia, and Siberia. At Niagara artificial graphite is made from coke. Its uses are:

(i) As a lubricant, when finely divided, for chains, or other machine parts moving over each other.

(ii) As a paint or polish for iron or steel (stoves, grates, etc.) and as a protection from rust.

(iii) When mixed with clay it is converted into blacklead pencils.

In addition to the two crystalline forms of carbon, there are several non-crystalline varieties:

Coal. This contains 80 to 95 per cent. of carbon. It is used for fuel and for the preparation of coal-gas and coke.

Soot and Lampblack. The coal used in a grate is not burnt away completely. Soot (carbon) settles in the chimney and either falls, making a dirty mess, or gets on fire. The chimney then has to be swept, or 'sweeled,' to get rid of it.

Lampblack can be got from a lamp flame by putting

a cold object in it. If a lamp-glass be removed from a lamp the flame becomes smoky. Any flame without sufficient draught will deposit lampblack. If turpentine or camphor is burned in a metal or earthenware dish an abundant supply of lampblack may be collected.

Soot and lampblack are not 100 per cent. pure but contain a little of the substance being burned, or some of their products. They make a dirty mess on the hands, and on rubbing a little between the fingers and thumb they appear to be very finely divided. Lampblack mixed with oil is made into printer's ink.

Wood-charcoal. When a piece of wood is lighted it burns away, leaving nothing but a little ash. But if the wood is heated so that the air cannot get to it water, gas, tar, etc., come off, and a porous, black, amorphous substance called wood-charcoal remains. Coconut shell makes very good wood-charcoal. Wood-charcoal is used for absorbing gases—generally noxious ones. 1 c.c. of carbon will absorb 200 c.c. of ammonia. Made into charcoal biscuits and swallowed, it absorbs the gases produced in the intestines which give rise to the feeling of indigestion.

Animal Charcoal. This substance is only about 10 per cent. carbon, the rest being bone-ash, which is mainly calcium phosphate. It is got by heating bones out of contact with air. It comes as a shock to many people to learn that this is used in refining sugar, the crude sugar being brown. When a solution is boiled with animal charcoal and the liquid filtered the filtrate is quite clear and colourless, the charcoal having absorbed the colouring matter.

Although diamond, graphite, and charcoal are so different in appearance and properties, they are

essentially carbon, and when burned in air or oxygen carbon dioxide is formed in each case. This could be proved by heating them in a current of air, or, better still, oxygen, and passing the gas produced into lime-water. Most people take this statement on trust, as Sir Humphry Davy carried out this experiment and diamonds are too expensive to burn away.

Carbon Dioxide

Carbon dioxide had been doing its deadly work for thousands of years before it was known to exist. People were poisoned by it in unventilated rooms, wells, caves, etc. Yet this animal poison is utilized by green plants (see Chapter XXII).

Van Helmont (1577–1644), who discovered it, called it 'gas sylvestre' (the wild gas of the woods). Joseph Black (1754) liberated it from chalk by adding a dilute acid. He called it 'fixed air' or 'chalk gas.'

Occurrence. (1) It is formed when substances such as coal, wood, paper, hay, and oil, all of which contain carbon, burn in air, when certain substances—*e.g.*, sugar—ferment, and when animals breathe out, or exhale. The amount of carbon dioxide in the atmosphere is normally ·03 per cent.

(2) It is present in mineral waters, caves, and deep wells. It is emitted by volcanoes. It is two and a half times as heavy as air and tends to settle at the bottom of wells, and is a danger to animals sleeping near the ground in a heavily-laden carbon dioxide atmosphere.

Tests by which it may be recognized. (1) The ancients detected its presence in large quantities by lowering a lamp into it. If the light went out the air

was considered to be dangerous to man. (Such a test is described by Pliny.)

(2) In large or small quantities it turns limewater white.

Preparation in the Laboratory. Fit up the apparatus shown in Fig. 152.

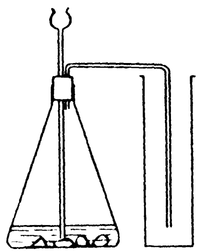

FIG. 152

The flask and thistle funnel are arranged as in the hydrogen apparatus. The delivery tube is shaped so that the gas can be collected by heavier-than-air displacement, or downpour. The end of the delivery tube extends to the bottom of the jar, so that the air is swept more completely out. Put in the flask any carbonate and add a solution of any acid. Generally some form of calcium carbonate—limestone, marble, or chalk—is used, and the acid is either hydrochloric, sulphuric, or nitric. Effervescence takes place, but as the gas is colourless it is impossible to see when the jar is full. A lighted splint lowered into the jar goes out at the carbon-dioxide level. From the carbonate and the acid used it is easy to name the salt left behind in the flask. Sulphuric acid gives sulphates, hydrochloric acid chlorides, and nitric acid nitrates.

Calcium carbonate + hydrochloric acid
→ calcium chloride.

When the residue in the flask is filtered and evaporated down crystals of calcium chloride can be obtained. It is very deliquescent—*i.e.*, it becomes wet when exposed to the air—and is used for drying gases.

Experiments with the Gas. (1) Add a little water to one jar. Shake up and add litmus papers. The blue

litmus paper is turned red, as some of the gas dissolves in water to form carbonic acid.

(2) Add a little limewater to another jar. It becomes white owing to the formation of some calcium carbonate. Leave the liquid at rest, and a white sediment collects at the bottom of the liquid. How could you prove that it is a carbonate?

(3) Leave a jar of carbon dioxide on the bench with the plate removed. Test with limewater after fifteen minutes to see if the gas is still there. Gases, including air, are perpetually in a state of movement, and will pass out of vessels containing them, travel across a room, and even pass through earthenware, rubber, etc. This movement is known as diffusion, and the lighter the gas the more quickly will it diffuse. Liquids and solids will diffuse, but not so readily as gases.

(4) Carbon dioxide was collected by downpour on the assumption that it is heavier than air. Another experiment will show that it is. Place a jar of air on the bench and over it place a jar of carbon dioxide, mouth to mouth. Remove both glass plates for ten seconds, replace them, and test each jar for carbon dioxide.

Or 'pour' some carbon dioxide over a lighted splint or candle (Fig. 153). It goes out. Carbon dioxide is used in many fire-extinguishers. Sand, water, a blanket, carbon tetra-chloride are all used to put out fires, but there are many fire-extinguishers based on the use of carbon dioxide. Soda crystals (carbonate of soda) and sulphuric acid are in separate compartments of the extinguisher. When it is inverted the two substances meet and carbon

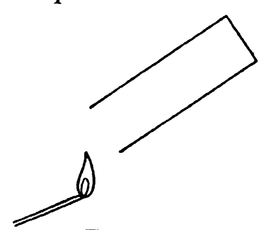

FIG. 153

dioxide is rapidly evolved. There is always a pressure of gas ready for emergency.

Lethal Chambers. Carbon dioxide is also used for lethal purposes—*i.e.*, it puts unwanted animals into a state of forgetfulness from which they never awake. The dog or cat is placed in a lethal chamber and supplied with carbon dioxide.

Combustion. Carbon dioxide will neither support combustion nor is it combustible. It is one of the products of combustion of substances containing carbon. Coal, wood, paper, straw, garden refuse, etc., all burn in air. Carbon dioxide is always produced; generally water also. Ash is left behind (mainly sodium and potassium carbonates), and if the air is not able to get readily to the burning material other chemicals may be produced—*e.g.*, coal yields coal-gas, tar, ammonia, etc.

When combustion takes place there may be flame, when it is called 'rapid combustion.' Often there is no flame, and the combustion is then described as 'slow combustion,' for the time taken is much longer. In both cases heat is produced and slow combustion ultimately passes into rapid combustion. This is a matter of great importance to the farmer. In Switzerland, where statistics have been kept over a long period, ·5 per cent. of the total hay crop is lost annually through the slow combustion of stacked hay, and, with the value of the buildings destroyed, the loss amounts to £750,000. In the U.S.A. the annual loss from the same cause is about £6,000,000. The phenomena of the sweating and heating of hay have been known since the dawn of agriculture, but it is still not clear why combustion takes place. Where the hay is dry

before it is stacked, and where ventilating shafts are made in the stacks, there is much less risk of any conflagration. A temperature of 250° to 300° C. is necessary before ignition of hay takes place. How this temperature is reached is as yet unknown.

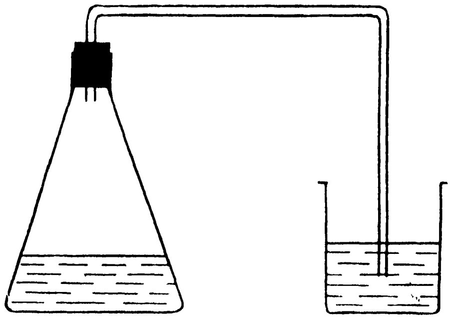

FIG. 154

Respiration. This action consists of two parts, the taking in of fresh air, called inspiration or inhalation, and the breathing out of impure air, which is known as expiration or exhalation. Expired air contains much more carbon dioxide than fresh air. Food is sometimes compared to fuel. A fire is replenished with fuel, and as it burns away heat is given out and one of the gases escaping up the chimney is carbon dioxide. There is carbon in all our food, and in a wonderful way it is oxidized within the body by the oxygen in the air we breathe. Heat is also produced, which maintains the body at 98·4° F. or thereabouts, and carbon dioxide is a waste gas.

Fermentation. A great many examples of fermentation might be given, but usually people refer to alcoholic fermentation. Make a solution of either cane- or grape-sugar. It must not be too strong. Add to it some yeast, and if the experiment is carried out in

winter keep the flask near a radiator (Fig. 154). The delivery tube of the apparatus dips into limewater.

Yeast is a tiny plant, and a small lump contains thousands of yeast cells, each of which is a plant. Inside each cell is a tiny dark speck called the nucleus, and the yeast plant grows by breaking up into two fresh cells, which grow for a short time and then break up themselves. Yeast plants require food, and as long as they are supplied with sugar and a few inorganic salts they live. A small amount of alcohol is produced as a result of their activity, and carbon dioxide passes into the limewater.

It will be seen that carbon dioxide is one of the products of the respiration of all living things, of the fermentation of sugar by yeast, of the rapid combustion of matter containing carbon, and of slow combustion and decay.

EXERCISES

1. Make different varieties of amorphous carbon and examine diamond and graphite.
2. Boil a solution of brown sugar with animal charcoal and see if the colour is removed.
3. Prepare sodium chloride from 10 grm. of soda crystals. Dry and weigh the sodium chloride.
4. Beginning with a piece of limestone, prepare lime, limewater, calcium sulphate, calcium chloride, and calcium carbonate again.
5. Ferment a sugar solution.
6. Test the gas coming off from a bottle of mineral water. Why is this gas put into the liquid?
7. Examine the school fire-extinguisher.
8. Add a few drops of acid to some old mortar. What does the effervescence prove?

CHAPTER XXII

INTERDEPENDENCE IN NATURE

We have seen that respiration, combustion of coal, oil, etc., decay, and fermentation are responsible for sending a very large amount of carbon dioxide into the air. Every ton of carbon burned uses over 2½ tons of oxygen; every ton of hydrogen burned uses 8 tons of oxygen to become water. In the British Isles over 200 million tons of coal are raised annually, and the burning of this removes 750 to 1000 tons of oxygen from the air every year. In other countries coal is being mined and burned to carbon dioxide, etc., yet the amount of oxygen and carbon dioxide in the air remains constant at about 20 and ·03 per cent. respectively. Why is this? Much carbon dioxide is dissolved by rain, but this does not account for the constancy of these two gases in the atmosphere.

In the first place the world's atmosphere is so extensive, and the carbon dioxide produced annually would occupy a very thin layer if spread uniformly over the surface of the globe. As all the people of the world could be packed on to the Isle of Wight, the carbon dioxide produced by their respiration does not appear so formidable. Secondly, the green parts of plants utilize carbon dioxide as food. It is too difficult for you at this stage to understand how this is possible, but the fact itself can readily be demonstrated.

Experiment. Take some leaves of a water-plant such as the common pond-weed or some water-cress.

Put some sprigs in a beaker of spring-water. This contains carbon dioxide dissolved in it. If spring-water is not available use water which is known to contain the gas. Place the beaker in the sunlight. Bubbles of gas come off, especially through the cut end of the stem and from the underside of the leaf.

Place a funnel, B, over the green leaves, A, and over the stem of the funnel place a test-tube full of water, C (Fig. 155); or a bell-jar may be used (Fig. 156).

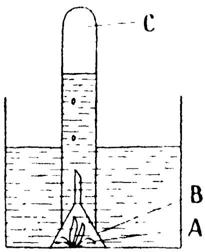

FIG. 155

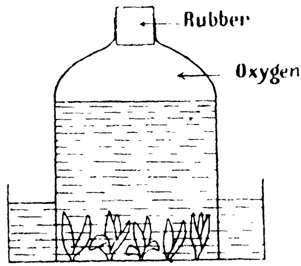

FIG. 156

Collect the gas and test it with a glowing splint. It is found to be oxygen. The green part of the plant, in the presence of sunlight, uses up carbon dioxide, returns the oxygen to the atmosphere, but retains the carbon. The above experiment has also been carried out (*a*) with distilled water containing no carbon dioxide, (*b*) in the dark, (*c*) with the roots and other parts of a plant which are not green, and (*d*) with green leaves which had been 'killed' by boiling or drying. In no case was oxygen obtained.

Conclusion. Only the living parts of plants containing this green colouring matter, called chlorophyll, can obtain carbon from the carbon dioxide of the air, and light is also required before the chlorophyll can do its work.

In performing this experiment see that the plant is a water-plant accustomed to live in water. Leaves of the bean, dandelion, lettuce, etc., will not do for this experiment because land-plants in water are not in their natural element, and do not act well. Further, as you will discover later, there is a supply of air associated with these plants which would be liberated whether photosynthesis (the term used to describe the action of light in causing chemical action) took place or not.

That the green part of a land plant behaves just like a water plant, has been proved by the following experiment (Fig. 157). Rest a large bell-jar on a glass plate or sheet of rubber so as to make it air-tight. Inside the bell-jar there is a growing plant and a candle mounted on a wooden stand. A strip of sand-paper is glued to the stand. The bell-jar is fitted with a rubber stopper, through which passes a solid glass rod to which is securely fixed a match. The glass rod is lowered so that the match is opposite the sandpaper.

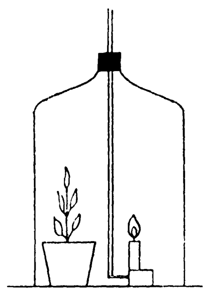

FIG. 157

Light the candle and place the bell-jar in position. A little vaseline smeared between the glass plate and the bell-jar will make the apparatus quite air-tight. Soon the candle goes out. Place the apparatus in the sunlight for a few hours. Strike the match against the sandpaper and relight the candle. It continues to burn for some time, showing that a fresh supply of oxygen has appeared. As often as the plant is left exposed to the sunlight the gas inside the bell-jar is re-generated. The bell-jar has not been raised throughout

the experiment so the oxygen must have been produced by photosynthesis.

The amount of carbon dioxide acted upon in this way is very great. Faraday says:

> A man in 24 hours converts as much as 7 oz. of carbon into carbon dioxide; a milch cow will convert 70 oz., and a horse 79 oz., solely by the act of respiration. That is, the horse in 24 hours burns 79 oz. of charcoal, or carbon, in his organs of respiration, to supply his natural warmth in that time. All the warm-blooded animals get their warmth in this way, by the conversion of carbon, not in a free state, but in a state of combination. And what an extraordinary notion this gives us of the alteration going on in our atmosphere! As much as 5,000,000 pounds [in 1867?] of carbonic acid is formed by respiration in London alone in 24 hours. And where does all this go? Up into the air. If the carbon had been like lead, or iron, which, in burning, produces a solid substance, what would happen? Combustion could not go on. As charcoal burns, it becomes a vapour and passes off into the atmosphere, which is the great vehicle, the great carrier for conveying it away to other places. Then what happens to it? Wonderful is it to find that the change produced by respiration, which seems so injurious to us (for we cannot breathe air twice over), is the very life and support of plants and vegetables that grow upon the surface of the earth. . . . They work together to make the animal and vegetable kingdoms subservient to each other. And all the plants growing upon the surface of the earth, like that which I have brought here to serve as an illustration, absorb carbon. These leaves are taking up their carbon from the atmosphere, to which we have given it in the form of carbon dioxide, and they are growing and prospering. Give them a pure air like ours, and they could not live in it; give them carbon with other matters, and they live and rejoice. This piece of wood gets all its carbon, as the trees and plants get theirs, from the atmosphere, which, as we have seen,

> carries away what is bad for us and at the same time good for them—what is disease to the one being health to the other. So are we made dependent, not merely upon our fellow-creatures, but upon our fellow-existers, all Nature being tied together by the laws that make one part conduce to the good of another.[1]

Interdependence and interrelation are better terms to describe this phenomenon than co-operation, for the latter term implies conscious effort. Many other such instances might be given. For example:

(1) Bees and other insects visiting flowers for honey and sweet juices bring about cross-fertilization (see Chapter XXV).

(2) Ants and aphides live together in colonies, and are mutually beneficial to each other.

(3) Birds destroy insect pests, help to distribute seeds, and fertilize the land. Guano is simply the droppings of birds which have accumulated for thousands of years (see Chapter XXVIII).

(4) In Northern Africa, Palestine, and Southern and Central Europe, there lives a bird known as the crocodile-bird or black-headed plover. It safely enters the open mouth of the crocodile and makes a meal of the small leeches which have fastened on to the gums of the crocodile and suck its blood. This association is beneficial to both crocodile and bird.

All the above are examples of symbiosis (or living together), and, even though the association is only temporary, it is beneficial to both organisms.

In other cases organisms live together without apparently benefiting each other. For example:

(1) The sucker fishes attach themselves to sharks,

[1] *The Chemical History of a Candle*, by Michael Faraday, pp. 140–141 (edited by W. R. Fielding and published by J. M. Dent and Sons, Ltd.).

turtles, whales, the bottoms of ships, etc., by a curiously modified front dorsal fin (Fig. 158). They are then carried rapidly through the water and when the carrier passes through a shoal of small fishes, etc., they can obtain food very easily, and when satisfied can

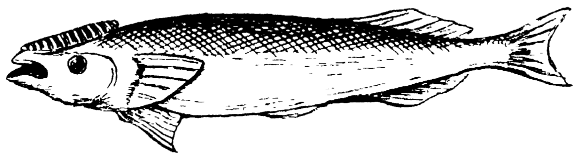

FIG. 158. THE REMORA

detach themselves at will. They do not benefit the carrier, and probably their presence is unnoticed.

(2) Living organisms frequently prey on each other. Of course every organism must get a food supply. Animals eat plants and other animals. But where two organisms live together and one is sapping away the strength of the other and giving nothing in return the former is called a parasite and the other the host. The ivy is a parasite, sending its roots into, and living on the food supply of, other trees. Vermin, pests, etc., are sometimes regarded as parasites unless we take the view that the filth on which they feed (plus a little of our food) might cause more serious trouble by its putrefaction if they did not consume it (see Chapter XXIX). Side by side with the destruction of pests and parasites should go the destruction of the environment in which they thrive (see Chapter XXIX).

Many very striking links are found in Nature.

(1) About fifty years ago rats became a serious pest in Jamaica, bringing about a partial destruction of the sugar plantations. The natives were alarmed, and the mongoose (an animal like a ferret which feeds on

snakes, rats, etc.) was introduced. The four males and five females multiplied very rapidly and destroyed the plague of rats, to the great joy of the natives. Then, in search of food, the mongoose began to destroy birds, lizards, crabs, harmless snakes, domestic animals, fruit, and vegetables. In consequence, insect pests previously kept in check by the latter animals now began to thrive and threaten the crops. In the end the planters had to give a shilling for every mongoose destroyed.

(2) Mice carried over in ships to Labrador spread so rapidly that they fouled the pasture on which the caribou fed. The caribou migrated, and the people lost part of their food supply. Wolves, bears, foxes, and birds were attracted by the great number of mice and quickly destroyed them; the caribou returned, and the wolves and bears retired.

(3) Huxley once facetiously remarked that British prestige on land and sea depended on our old maids.

They keep cats.

Cats go to the clover fields at night because they know they will find field-mice there.

As the field-mice are killed the humble-bees survive and pass from flower to flower fertilizing the clover.

A good clover crop means plenty of beef, and therefore our stout yeomen are able to man our ships and fight our battles on land and sea.

CHAPTER XXIII

LIVING THINGS

You will have no difficulty in describing the objects mentioned in the preceding pages as 'living' or 'non-living'—*e.g.*, Columbus, ships, Great Bear, carbon, salt, desk, flower, etc. Some have had life (or still have life); other things have never been alive and are called inanimate, or lifeless. Thus we can divide 'things' into animate and inanimate things.

Things
- Animate
  - Plants
    E.g., Flower
    Potato
  - Animals
    E.g., Columbus
    Red Indian
    Lion
- Inanimate
  E.g., Ship
  Great Bear
  Carbon
  Salt
  Desk

The science which deals with living things is known as biology, and it consists of two parts: botany, dealing with plants, and zoology, dealing with animals. Most people have considerable knowledge of biology because they have been imbibing it, in small doses, since they were born. For instance they know that:

(1) Plants have certain parts, roots, stem, leaves, etc.

(2) Plants do not move about to get their food, but the ground is tilled and the food put into the soil.

(3) Certain parts of plants are green. These parts, in the presence of sunlight, can remove carbon from

the carbon dioxide in the atmosphere and set free oxygen.

(4) Plants are grown from seeds. These are generally small and light in weight and are easily carried about by the wind. Thus plants appear in places where they have not been planted.

(5) Some plants are cultivated for their leaves, others for their stems, and others for their roots, etc.

(6) Each country has its own special plants, or flora —*e.g.*, we do not grow bananas, coconuts, banyan trees, etc., in this country.

In the same way, most people have gained some knowledge of animals. For example:

(1) Some animals have two legs, and some four legs; some animals have feather, others fur, others hair.

(2) Some animals eat grass and other vegetable matter—*e.g.*, the cow; other animals are meat-eaters and are said to be carnivorous—*e.g.*, the lion; other animals are omnivorous because they eat both vegetable and animal food—*e.g.*, the rat, man, etc.

(3) There is a big difference in the teeth of animals. Some teeth are specially adapted for cutting food—they are called incisors; other teeth are suitable for tearing food—such teeth are called canine teeth; other teeth are suitable for grinding food—these are the molars. Examine your own teeth. First find the four canine teeth, or eye teeth, two on the top and two on the bottom. Human beings have given up tearing flesh from other animals and so these teeth have gradually lost the fearsome character that the canine teeth of the tiger, lion, dog, cat, etc., still have. Between the canine teeth are the incisor or cutting teeth. Compare yours with the front teeth of a rabbit. The

back teeth are the grinders, or molars, and they are grooved.

(4) Some animals live in packs or herds, like wolves, elephants, rabbits; others live by themselves or in a family of father, mother, and children—*e.g.*, hares. Cats do not seem to need much society, but a mother cat will look well after her young until they are able to look after themselves.

Requirements of all Living Things. Although there is a wide difference between, say, a dandelion and an elephant, it is surprising how alike they are in many respects.

(1) All living things require air. Most animals would die if deprived of air for only one minute. Few persons can hold their breath for one minute. Plants also respire, and, while the green part of a plant is able to decompose carbon dioxide and return the oxygen to the atmosphere, living plants themselves require oxygen for respiration. Plants living in the open air get an adequate supply of oxygen, but greenhouses have to be ventilated if healthy plants are to be grown in them.

(2) All living things require water. By eating juicy plants and vegetables certain animals—*e.g.*, the rabbit—appear not to require water, but water is essential, either directly or indirectly. Lands without water are called deserts and few plants and animals are found there; such animals as are found there periodically leave the desert to satisfy their needs.

(3) All living things require food, and in the course of ages each kind of animal has cultivated a liking for, or been forced to eat, certain food. Some animals—*e.g.*, the lion and tiger—feed on animal flesh, and even

in the Zoo have to be supplied with their normal diet; other animals—*e.g.*, the elephant, monkey, giraffe—are vegetarians, living on grass, fruit, leaves, and seeds. Rats and human beings live on both animal and vegetable food. When the supply of food is short animals and plants die. If the farmer does not feed his soil with manures and fertilizers the crops gradually dwindle in amount; birds which are unable to get sufficient food and drink in the winter months die in great numbers, especially during January and February when the ground is often frostbound, and they cannot get water, insects, worms, or grain. Some animals are unable to alter their diet and die, although there is lying about them plenty of material on which other animals are thriving. Where there is a shortage of winter food in any land birds have acquired the instinct of migration. Some birds, for example, the swallow, are here for the summer and in autumn return to a warmer climate where food such as they require is abundant. On the other hand, large numbers of northern birds—*e.g.*, the starling—spend the winter with us. Other animals hibernate, that is, bury themselves and sleep during the winter. Such animals are tortoises, worms, snails, frogs, squirrels, bears, etc. They gradually waste away, getting whatever food they require to maintain their bodily heat by using up their own fat; so they appear emaciated, or nothing but 'skin and bone,' in spring when they come back to 'life' again (or into the world). Animals are then most ferocious and cunning. A roaring lion is evidently not in search of food. Some animals, like the squirrel, take with them a supply of food into their winter quarters.

At this point it may be advisable to explain the real function of food. Some people imagine it is to please or tickle the palate, and that chocolate is preferable to rice pudding, and trifle to bread. As a matter of fact food is to the body what coal is to a fire. If the coal will not burn there will be no heat. We eat food

(*a*) To keep us warm. Our bodies are maintained at 98·4° F. when the air around us is at a much lower temperature.

(*b*) To enable us to grow. We started as babies weighing only a few pounds, and we grow up to weigh 10 or even 20 stones, largely gained out of the food eaten.

(*c*) To repair the waste going on in our bodies.

All foods contain carbon, hydrogen, oxygen, and nitrogen. Sometimes there is a little phosphorus, sulphur, iron, potassium, calcium, etc., in food. In the case of animals food is taken in by the mouth and it passes first into the stomach and then into the intestines; certain parts are there used up or assimilated, and the other part is rejected as waste. In the case of plants the food is absorbed mainly by the roots in the form of solutions, and practically the same elements go to the making of a plant as are required by an animal.

Although foods can be expressed in terms of a few chemical elements, they must be presented in a suitable form. Neither plants nor animals could live on diamonds (carbon), magnets (iron), etc.

(4) All living things require a certain temperature. There is very little life in polar regions, where the ground is frozen throughout the year. Also, neither plant nor animal can survive if left for a few minutes

in boiling water; all are killed. One of the most difficult things to realize is that life, as we know it, is only possible between a small range of temperature, say, $-50°$ and $100°$ centigrade.

(5) Most living things require light—if not sunlight—although deep-sea fish, nocturnal animals, etc., seem to require very little.

If the above five conditions are satisfied a plant or animal will live and grow and develop. But no living thing can live for ever. After a short span of life it dies and decomposes, passing into dead chemical substances, unless some other living thing uses it up as food.

Every living thing is able to have young and so propagate its species. Plants produce seeds, animals have young animals which pass through the stages of birth, infancy, adolescence, full growth, and death. Biologists are trying to produce new plants and animals, trying to prolong life, trying to make it better and happier, especially for human beings. But so far they have failed to produce what the alchemists called the "Elixir of Life," by which perpetual youth could be secured. Certain whales are said to be over 1000 years old, certain trees still living were planted before the Norman Conquest, a few men and women live to be over a hundred years old, whereas some insects live only a few minutes.

CHAPTER XXIV

SOME FORMS OF LIFE

If specimens of different living things were placed before you you would agree that some forms might be described as 'low forms' of life with respect to others. Germs, snails, worms, frogs, etc., are described as inferior to lions, tigers, and horses. Man is considered—by himself—to be the highest form of creation.

In a small book like this we can only consider a few types of living things. One of the lowest forms of life is the yeast plant. You cannot see it with the naked eye. It is present in the soil and is always floating about in the air. If it drops into a suitable medium it grows and multiplies. For the study of the yeast plant it is best to purchase yeast from a grocer's shop. It does not appear much like a living thing but more like a piece of putty.

Experiment. Repeat the experiment described at p. 192. Make a solution of sugar—either cane (or beet) sugar or grape sugar. Pour it into a flask and add a few pieces of yeast. Stopper the flask and fit it with a glass tube which dips into limewater.

Put the whole apparatus into a warm place (not hot) and leave it alone for a short time. Gradually the yeast begins to use up the sugar in the solution and the liquid is seen to effervesce, or be filled with bubbles. These pass into the limewater and turn it white, showing that the gas is carbon dioxide. Next day smell the

liquid in the flask: it will be found to have an alcoholic or fruity smell. Thus,

Yeast + sugar solution → alcohol + carbon dioxide.

Unless the yeast is transferred to another supply of sugar, it dies both from shortage of food and the poisonous effect of the alcohol. The conditions of life required for the cultivation of yeast are now well known. They are:

Food. Sugar solution plus certain salts in small quantities.

Temperature. The best temperature is about 25° to 30° C. Yeast can be killed by boiling the liquid in which it is growing.

FIG. 159. YEAST CELLS MAGNIFIED, SHOWING FORMATION OF BUDS

The yeast plant is not green, and so does not require light. A plant consists of only one cell, and it reproduces itself by budding, or division. Under the microscope a yeast cell and a colony of cells appear as shown in Fig. 159.

THE BEAN PLANT

EXPERIMENT. Examine a bean seed (Fig. 160). It is large, and the skin is hard and rough. It has a scar on one edge, showing where and how it was joined to the pod. The skin can be split open with a knife and peeled off. It is better to soak a few beans in water for 24 hrs., after which the skin is much more easily removed. The inside can be separated into two thick white portions called seed-leaves, and between them, and joined on to them, is the embryo, or plantlet

(Fig. 161). The seed-leaves provide food for the baby plant. It makes a kind of milk when the water in the ground oozes through the skin. The latter protects the baby plant and keeps the food together.

The plantlet has a little root, and a shoot consisting of two tiny plant-leaves showing the veins. This embryo is a living thing. If the seed is kept dry no change takes place and the embryo may remain

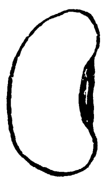

FIG. 160. COMPLETE BEAN, SHOWING SCAR WHERE IT WAS JOINED TO THE POD

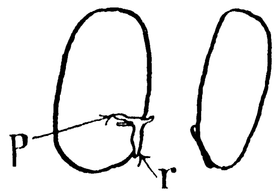

FIG. 161. THE PLANTLET OR EMBRYO

p is the plumule, which grows towards the light; *r* the radicle, which grows downward.

dormant for years. But put it into suitable soil, where it will have water, food, warmth, light, and air, and it will grow and develop above ground.

Many seeds show this three-fold structure:

(1) The embryo or baby-plant.
(2) The two seed-leaves, or cotyledons, which, with water, make a milky-looking fluid which is the food of the baby plant until it can get food itself from the soil.
(3) A tough outer skin or covering.

In order to watch the growth of seeds a seed-box should be procured. This may be any sort of box with one side replaced by a sheet of glass. Soil or sawdust may be used in the box, and the seeds planted between

the glass and a sheet of blotting-paper (or, where the latter is not used, as near to the glass as possible) so as to offer a good view of the developing seed. Any water added to the soil passes through the blotting-paper and gives the seed all the moisture that it requires (Fig. 162).

Until seeds are actually required they should be kept in a cool, dry place. All seeds sold in this country are guaranteed by law to produce a certain percentage of successful sproutings or germinations, the percentage depending on the particular kind of seed.

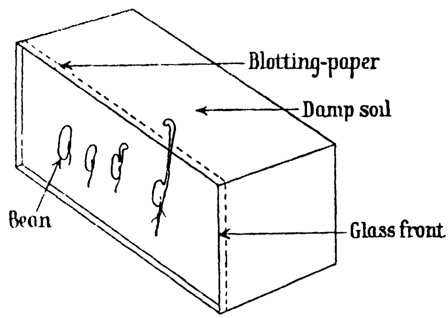

Fig. 162

Experiment. Place different kinds of seeds on a damp flannel resting in a saucer containing a very little water. Keep in a warm place. Note when the seeds germinate, sprout, or begin to grow. Do all kinds take the same time to germinate?

Returning to the bean. As it soaked up water the outer skin grew soft and began to swell. Next the seed germinated and the root appeared through the skin and began to grow downward. Its growth may be measured from day to day by simply putting a ruler in the soil by its side. Next the shoot appeared and, unlike the root, it grew towards the light. For some days the baby plant lived on the food in the bean, so that the latter grew softer and thinner. Then the shoot appeared above the ground, after which the plant gradually established itself in the soil with power to collect its own food through its roots. Unless the soil

is kept damp the soluble food cannot dissolve, and no plant can absorb dry chemicals.

Draw the bean plant, showing root-system, stem, and foliage leaves as they appear.

Seeds of mustard, cress, peas, lettuce, etc., should be germinated. The mustard seed develops somewhat similarly to the bean, but the seed-leaves are carried above the ground into the air. Soon the skin is cast off

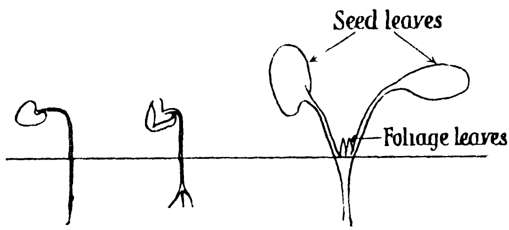

FIG. 163

and the white seed-leaves, now in the air, become green leaves, the first leaves of the plant. Later, two foliage leaves, of a different shape, grow out between the seed-leaves (Fig. 163).

The potato is not a seed, although growers refer to seed-potatoes. You can sprout a number of potatoes without putting them in the ground. The sprouts grow from the eyes. The potato is really a portion of swollen underground stem, or a tuber. When the potato is growing strongly flowers appear, and potato seeds may sometimes be collected from them if certain precautions are taken. But real potato seed is rarely used by growers, seed-potatoes being more convenient.

If you have opportunities you should have a small garden in which to carry out experiments. The temperature outside is lower than it is inside the school, and germinations may not be so successful if carried

out too soon. Peas and beans are hardy enough to be planted in early March; cabbages, turnips, etc., a little later; but the ground is usually not warm enough for beet, carrots, and cauliflowers until April. Amateur gardeners generally plant their potatoes somewhere about Good Friday; this is a movable day, so the day and not the date is associated with the planting.

The soil must be well dug and broken up into fine particles or the roots cannot easily penetrate it. While the soil should be watered (in the absence of rain) it must not be made too wet. Water has such a high specific heat that wet ground is cold ground, and one of the conditions of growth, a certain temperature, may not be satisfied.

EXERCISES

1. Ferment some sugar solution by means of yeast. Pass the carbon dioxide into limewater. Put a little of the yeast after fermentation under a microscope and look for the cells.

2. Walk through a field or wood and make a list of the plants seen, describing (*a*) appearance—whether erect or fallen or creeping, etc.; (*b*) whether in flower and, if so, colour, number, and distribution; (*c*) whether the leaves are thin, thick, smooth, hairy, prickly, etc.

3. Visit the park and note the gardening operations being carried out by expert gardeners—*e.g.*, the time of pruning roses, potting geraniums, planting out of bulbs, etc.

4. Using the seed-box or damp flannel or sawdust, germinate the following seeds: peas, beans, beet, lettuce, carrots, mustard, cress. Take the times required. Also sprout a number of potatoes. Compare the number of sprouts, colours, etc., in different varieties of potatoes.

5. Find the percentage of germinations of the above seeds, using at least ten seeds of each.

6. Make a list of birds that you observed on your walk and make notes on: colour, size, shape, beak, legs, song or language, etc.

7. Draw the plants and birds that you refer to in Questions 2 to 6.

CHAPTER XXV

THE COMPLETE PLANT

It will take a long time for some of the seeds you have germinated to live their full lives. If they are planted in the garden, or greenhouse, or schoolroom, you will be able to watch their progress. You should discover many things that are not likely to be mentioned in class. *E.g.*, how long does it take the potato, after it has been planted, to appear above the ground? Is the time the same for sprouted and unsprouted potatoes? How long is it before the plant flowers? Do cabbages, onions, carrots, etc., flower and seed? Whenever possible you should study the complete plant—*e.g.*, the dandelion, buttercup, daisy, nettle, blackberry, fruit-trees, hawthorns, wild rose.

Roots. Pull up a few plants (weeds will do) and you will see that each plant has a part underground, known as the root. Wash away the soil from the root. Usually there is a main root, or tap-root, from which branches protrude in different directions. These branches are more or less symmetrically distributed around the tap-root, because in this way the roots most adequately fulfil one of their functions, namely, to fix the plant in the soil. An unsteady plant would have its food supply interfered with, as it would not always be in touch with the supplies of soluble salts which enter by these roots.

Plants are fixed to one spot, and so must get all their food from a very limited area. Some plants accumulate

a reserve of food for later use, and are able to survive through the winter. Often they sacrifice all their parts above ground when the cold weather arrives and retire below the surface of the ground where it is warmer. In some respects this is like hibernation in the case of animals. Any plant that stores up a reserve of food must first make it, and in the summer and autumn they make more food than they actually need for their immediate requirements, and the surplus is stored in swollen underground parts. In some cases this store of food is in the roots, as in beetroots, carrots, turnips, radishes, cassava (tapioca); in other cases it is in underground stems, as in the potato and arrowroot plants; whereas in plants like onions, leeks, bulbs, the rain drains into the underground portion of the leaves which become thick and fleshy, and the upper, green portion of the leaves withers away. A few such plants might be left in the school garden throughout the winter to see if they flower and seed during the second year.

If this cannot be done various vegetables may be planted. (*a*) Onions sprout in the house. Plant one in a large pot and watch its development. (*b*) Cut away the top portion of a carrot or turnip and plant it in moist soil or in a saucer containing water. A most beautiful plant will appear, utilizing the underground food reserve of the plant (Fig. 164).

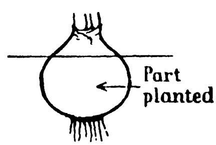

FIG. 164

Slender branches called root-fibres grow out from the tap-roots. They travel away from the stem, pushing their slender fibres into the small openings in the soil. That is why ground should be well dug and broken up, to make it easier for these pointed root-fibres to advance.

Two things cannot occupy the same place at the same time, and as the tap and fibrous roots and the root-fibres thicken in the course of years, they may cause damage to roadways and walls.

> In tropical countries the destruction of buildings is universally caused by the power of the growing roots; and neither conquering nations, nor earthquakes, nor fires, nor tempests, nor rain, nor all put together, have destroyed so many works of man as have the roots of plants which have all insidiously begun their work as slender fibres.[1]

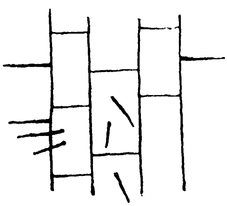
FIG. 165

Food is absorbed by the root-hairs, which are delicate long cells, standing out from the root-fibres (Fig. 165). They can readily be seen by means of a microscope.

These facts may be summarized thus:

Roots that nourish plants as they grow | Roots that lay up a reserve of food to nourish the plant during the winter

ROOTS

Tap-roots | Fibrous roots

Root-fibres

Root-hairs which collect food

Of the five requisites of living organisms, namely, water, food, air, warmth, and sunlight, the root requires the first four. These may be secured by proper

[1] *Primer of Botany*, by Sir J. D. Hooker, pp. 29–30 (Macmillan and Company, Ltd., 1876).

cultivation of the soil. Manures and fertilizers may be added to replace food used up by plants, and water may be necessary in times of drought.

FOOD	*Natural:*	Soil contents, droppings from birds and animals. Contributions of thunder-storms (Chapter XVII).
	Artificial:	Manures and fertilizers.

The Stem. This is more or less vertical, but it sends out laterals or side-growths. It is generally above the ground but in the case of the potato, cowslip, and some other plants part may run horizontally below the ground. Stems are distinguished from roots by bearing

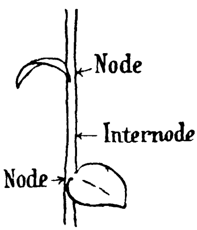

FIG. 166

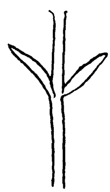

FIG. 167

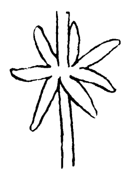

FIG. 168

leaves, buds, and flowers. Some trees have one long stem (like most palms) or they may consist of many branches. Leaves grow out from the stem at points called the 'nodes,' and the space between two consecutive nodes is called an 'internode' (Fig. 166).

The leaves may be alternate (Fig. 166)—*e.g.*, vine and ivy—opposite (Fig. 167)—*e.g.*, maple and geranium—whorled (Fig. 168)—*e.g.*, woodruffe and bedstraw—or tufted—*e.g.*, larch, cedar, and pine.

The stem may be round, fluted, square, etc. Some stems are erect, others drooping, others twining (like that of the convolvulus), and others underground. The

leaves are tilted at various angles to the stem so that the rain may drain to, or away from, the roots. Rhubarb leaves drain the rain to the roots (Fig. 169), whereas such plants as the rhododendron and other evergreens drain the water away, and it is usually very dry under the tree.

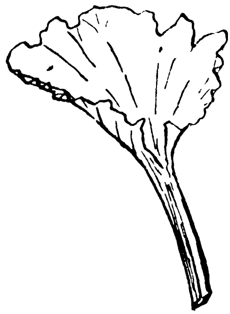

FIG. 169
RHUBARB LEAF

Leaves. The chief functions of leaves are as follows: (1) They expose a large surface to the action of the sun's light and heat; consequently, photosynthesis takes place on a very large scale. Like animals, plants respire, although on a much smaller scale. They respire both during the day and the night, but in the daytime they use up about thirty times as much carbon dioxide from the air as they produce. During the night-time they produce a little carbon dioxide as a result of respiration, and do not absorb any from the atmosphere; but the popular idea that they are dangerous in a sleeping-room on that account is greatly exaggerated. A single candle or gas-flame produces more carbon dioxide. Moreover, air-currents through the windows, under the door, and up or down the chimney should dispose of all danger.

(2) They are the lungs of the plant and provide for the evaporation of large quantities of water.

Some leaves are deciduous—*i.e.*, they fall annually—*e.g.*, the oak, apple, and hawthorn. Others, are persistent, or evergreen—*e.g.*, holly and laurel.

Some leaves are simple (oak) and some compound—*i.e.*, made up of separate leaflets (ash, horse-chestnut, rose, pea, bean) (Fig. 170).

Leaves may be, for example, entire (privet), serrated (lime), or toothed (holly) (Fig. 171).

Other characteristics that should be noted by the student are colour (compare the colours of different

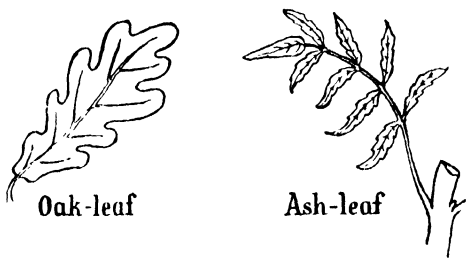

FIG. 170

varieties of potatoes and observe the red colour of the copper beech), smell (compare garlic, blackcurrant, and mint), and texture (compare the texture of the soft vine leaf and the hard privet leaf).

The Flower and Fruit. At the end of certain limbs or stalks flowers appear. These are the most important

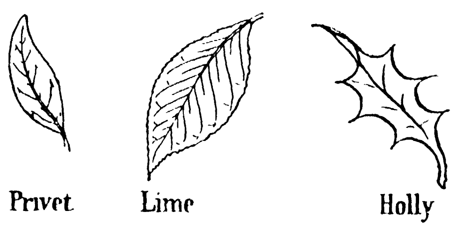

FIG. 171

means by which plants are reproduced, or perpetuated. Some plants have only one flower, springing from a single stalk (the tulip); other plants have many flowers growing out from the axils—*i.e.*, between the leaf-stalk and the stem; and yet other flowers appear in crowded

heads of flowers, usually called florets (the marigold, dandelion, thistle, coltsfoot, daisy).

A typical flower consists of a stem carrying four circles or whorls of coloured leaves (Fig. 172).

When people speak of the 'flower' it is generally the corolla that they have in mind. Often it is beautifully or distinctively coloured, either to attract visitors or to warn away animals that would dislike its bitter taste. Grazing cattle often miss the buttercups.

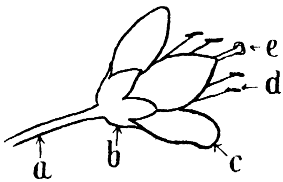

FIG. 172. PATTERN OF A COMPLETE FLOWER

a, stalk or peduncle; *b*, calyx, composed of sepals; *c*, corolla, composed of petals; *d*, stamens; *e*, pistil.

The calyx and the corolla are also protective, for the most important part of a flower is inside the petals. If the two outer whorls are pulled off or bent back the stamens and pistil can be readily examined.

Fig. 173 shows the arrangement of the stamens and pistil of the tulip. The flower has six petals in the

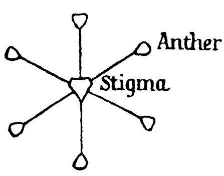

FIG. 173

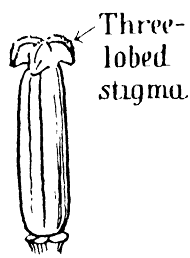

FIG. 174

corolla, six stamens, and one pistil containing a three-celled ovary with one style and a three-lobed stigma (Fig. 174). Each stamen broadens out at the top into an anther, which is covered with a fine powder called 'pollen.'

Some plants have certain of the above parts missing. Many have either no pistil or no stamens, the missing organ being found on some other incomplete plant. Many flowers have only one stamen and one pistil.

Some of the pollen falls on the sticky pistil, and the ovary at the base of the latter may become fertilized. This act of fertilization leads to the formation of the fruit or seed. The pistil is a long hollow stem, with the stigma at the top and the ovary at the bottom (Fig. 175). The pistil may contain many cavities, each of which contains one or more minute bodies destined to become seeds.

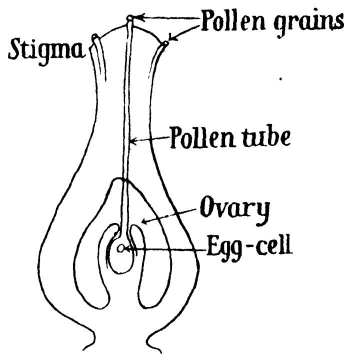

Fig. 175

When the pollen has reached the ovary, the flower has done its work and it withers away. (In time all flowers wither whether they have been fertilized or not.) Then a remarkable development occurs in the ovary, culminating in the formation of the seed. Some flowers give only one seed—*e.g.*, the cherry, plum, nut. Others give many—*e.g.*, the apple, pear, pea, bean. Sometimes the seed is surrounded by a fleshy mass of delicately coloured and pleasant-tasting composition. It is not the real 'fruit,' although it is so called in popular speech. It is so displayed to attract birds, insects, and other animals, which eat the pulp and help to disperse the seeds over a wider field and thereby increase their chances of survival. Darwin removed eighty seeds from one foot of a bird.

Fig. 176 shows an apple with the five carpels, each containing one or two seeds. Fig. 177 shows a strawberry which is a fleshy mass covered with ripe seeds. 'Fruit,' in the popular sense, is attractive to the eye

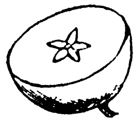

FIG. 176. SECTION OF AN APPLE

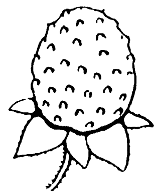

FIG. 177. THE STRAWBERRY

and to the taste, but it is not highly nutritious, especially as the seed is often rejected.

In examining a flower count

(1) The number of sepals in the calyx.
(2) The number of petals in the corolla.
(3) The number of stamens.
(4) The number of pistils.

It is often easier to remember plants by noting differences as well as resemblances. For example, broom and gorse are often confused.

BROOM	GORSE
Leaves made up of separate leaflets (three).	Leaves replaced by green spines.
Leaves not opposite.	Twigs prickly or thorny.
Flowers yellow.	Flowers yellow.

You should consult a flora in order to decide the name of a plant. *E.g.*, there is an order of plants called 'Compositæ,' each member of which has a 'head' of florets. This family includes the marigold, chicory, hawkbit, dandelion, thistle, burdock, and many others.

They not only show resemblances, which makes it reasonable for them to be included in the same order, but they also show differences, and a flora will help you to decide the name of the plant under inspection.

Seeds are dispersed in different ways. Some fall to the ground quite close to where they are grown, the pulp rots, and in time the seed sinks into the ground and may become a plant. The ground may be thick with other plants, and a struggle for existence begins in which some of the plants must perish from lack of food, air, water, or light. Other seeds roll some distance away and they may find the spot comparatively free from plants, so that it is possible for them to become established there. Some seeds are very light, and the wind may blow them miles away from their place of birth; in fact, some seeds are provided with plumes so that the wind will carry them along—*e.g.*, the dandelion, thistle, willow, poplar. Other seeds are dispersed by birds or water.

Many plants are eaten before they have completed their life-history, for we eat the roots of carrots, turnips, and radishes, the underground stem of the potato and artichoke, the leaves of cabbages and lettuce, the stalk of the celery and rhubarb, the flowers of cauliflowers and brocoli; and the fruit of the tomato, strawberry, and nut.

Fertilization. Some plants are self-sterile—*i.e.*, the pollen will not fertilize its own ovary; others are self-fertile. The pollen of one flower will fertilize another similar flower and produce, in most cases, a healthier specimen. This is known as cross-fertilization or cross-pollination. Cross-fertilization is brought about by

(i) Wind which scatters the pollen.

(ii) By human agency. Gardeners at midday often shake the wires on which their tomato plants are being supported, so that the pollen is scattered.

(iii) Through the agency of insects. These visit flowers to obtain nectar and brush against the stamens of one plant, transporting the pollen to the pistil of another flower.

New Plants. For some mysterious reason plants and animals tend to deteriorate in quality unless supplied with a new strain or 'new blood,' and scientists are always on the look-out for new plants.

Potatoes grown in the same soil for a few years become susceptible to disease, and the tubers are often too small to sell. To keep the stock healthy tubers grown in cold countries are used as seed-potatoes. Scottish seed-potatoes are sown very largely in England. Even then the life of a potato variety is only reckoned at 25 to 50 years, after which it begins to deteriorate. Potato growers by means of cross-fertilization try to introduce new varieties. They even visit distant places such as Peru to obtain varieties of wild potato with which to harden our existing varieties and make them immune to such diseases as wart disease. Wheat takes a certain number of hours of sunlight to ripen it fully, and until recently it could not be ripened within the Arctic circle. New varieties, which will ripen in a shorter time, have now been produced by cross-fertilization. Consequently the area of wheat-lands has been greatly increased. One disease of wheat is known as 'rust,' but Professor Biffen has now produced varieties immune to this disease. The loganberry is a cross between the blackberry and the raspberry.

The same principle operates in the animal kingdom.

Our history books remind us how the British race is compounded of Celtic, Anglo-Saxon, Norman, and other elements.

The mule is the offspring of a mare and a male ass. Mules are stronger in constitution than horses, less liable to disease, and more easily pleased with food, while they are stronger and bigger than asses. Though obstinate like the latter, they are reputed to be very sagacious and sure-footed.

EXERCISES

1. Shake up some soil with water, filter, and evaporate the solution to dryness. Is there any solid plant-food?

2. Examine the roots of a few wild flowers, vegetables, etc. Can the root-hairs be seen through a magnifying glass?

3. Collect leaves of hawthorn, oak, ash, beech, maple, blackberry, apple, etc. Carefully examine both sides of the leaves and draw them.

4. Place a number of peas or beans in a jar covered with a glass plate. See if there is any carbon dioxide produced after they have germinated.

5. Devise an experiment to show that plants respire (*a*) during day-time, (*b*) during the night-time or in the dark.

6. Examine in the following ways plants available according to season and locality:

   (*a*) See how the leaves are arranged.
   (*b*) How many sepals, petals, stamens, pistils are there?
   (*c*) Describe the number of seeds thus: solitary, few, many.
   (*d*) See if the stamens and pistil are of the same length. Are both present in all the flowers that you have examined?
   (*e*) Draw stamens, pistils, and ovaries which show unusual features.

CHAPTER XXVI

INSECTS

INSECTS are very numerous, and there are about half a million different species, exceeding in number all the other members of the animal kingdom put together. Most of them can only be examined when dead. They are killed immediately by being dropped into boiling water, or by being placed in a box or flask and chloroformed. Well-known insects are: fleas, lice, aphides, water-boatmen, flies, gnats, daddy-long-legs, butterflies and moths, beetles, dragon-flies, earwigs, cockroaches, grasshoppers, locusts, crickets, bees, wasps, and ants. What, then, are the essential characteristics of so many widely differing animals? They are all 'invertebrates'—*i.e.*, without backbones—and in looking at them closely you will find that their bodies are divided into three separated parts: (i) the head; (ii) the front body, or thorax, on which the six legs and the wings, if any, grow; (iii) the hind portion, or abdomen. However long this section may be it never grows any legs on it.

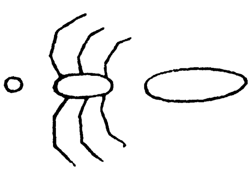

FIG. 178. PLAN OF AN INSECT

Some animals are frequently mistaken for insects—*e.g.*, the spider—but its head is not clearly separated from the thorax and, moreover, it has eight legs (Fig. 179).

Neither is a centipede an insect.

The body of insects is divided into rings or segments. The thorax has three segments, and the abdomen

shows many (generally ten). These segments enable the insect to bend, and to breathe. You can see the abdomen of a live insect moving in and out. On some of the rings there are small dots. These are the breathing holes and the air enters at these points; insects do not breathe through the mouth.

Fig. 179. A Garden Spider

On comparing certain true insects, such as the house-fly, the daddy-long-legs, the wasp, and the bee, you will see that they have not the same number of wings. Some, like butterflies, bees, and wasps, have two pairs of wings; a daddy-long-legs (a crane-fly) has only one pair; but behind its wings are two little knobs (*k*) called 'balancers,' the stumps of another pair (Fig. 180). Fleas have no wings.

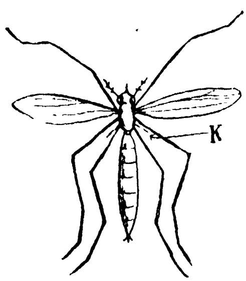

Fig. 180. A Daddy-long-legs

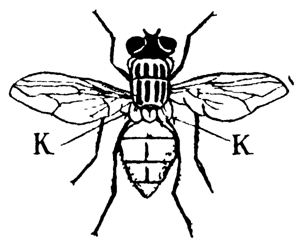

Fig. 181. A House-fly

The house-fly also has two wings and two stumps, or balancers (Fig. 181). The insects mentioned in the opening paragraph of this chapter have been classified according to the number and characteristics of their wings. Every species of insect is called by a word ending in 'ptera,' which is derived from Greek *pteron*, meaning 'a wing.' The following table need not be

learnt by heart at this stage. It is to show that where there are thousands of different members of the same big family some method of classification has to be adopted. The same idea has to be followed in our libraries. A library of 100 books need not be classified, although it is better to have all on one subject together. In a library of half a million books scores of different classes must be made. Science books are divided into sections on chemistry, physics, botany, zoology, astronomy, etc. Then the thousands of chemistry books have to be divided up into classes of books dealing with the history of chemistry, organic chemistry, inorganic chemistry, qualitative analysis, and many other divisions. Just as 500,000 books need to be classified, so there is just as much necessity to classify the same number of insects. All insects have the threefold division into head, thorax, and abdomen, also six legs, so the basis of classification is the wing. Thus,

Order	Meaning	Examples
A-ptera	Without wings.	Fleas, lice.
Hemi-ptera	Half-winged (the wings are horny in front and transparent behind).	Aphides, water-boatmen, plant-bugs.
Di-ptera	Two-winged.	Flies, gnats, daddy-long-legs.
Lepido-ptera	Scale-winged (covered with fine scales).	Butterflies, moths.
Thyoano-ptera	Fringed wings (four narrow).	Thrips.
Coleo-ptera	Sheath-winged. The front wings are horny, forming wing-cases.	Beetles.
Neuro-ptera	Nerve-winged. The wings are covered with a network of nerves.	Dragon-flies.
Ortho-ptera	Straight-winged. Wings fold in straight folds like a fan.	Earwigs, cock-roaches, grass-hoppers, locusts, crickets.
Hymeno-ptera	Membrane-winged. Wings of transparent membrane.	Bees, wasps, ants.

The legs of all insects are jointed: the house-fly has legs which are nine-jointed, the cabbage-white butterfly legs which are five-jointed. The last joint ends in two small claws for grasping things, and a pad which enables the insect to cling to a smooth surface.

On the head are two feelers, or antennæ, and a proboscis which ends in a sucker. Food is sucked up into the mouth by means of the latter.

Habits. Some insects bite. The tsetse-fly found in South Africa is one inch in length. It bites horses, cattle, man, and other animals, and may pass the germs of 'sleeping sickness' into the blood. The horse-fly has a specially developed proboscis with which it can pierce the hide of the horse and lay its eggs there.

The common house-fly does not bite, but it lives on vegetable and animal food. We regard it as a pest, but we are largely to blame for any harm that it does. It acts as a scavenger and consumes matter which might putrefy and cause other diseases. The real danger of this fly is that it obtains its food from questionable sources and introduces filth and disease into our food. Side by side with the destruction of this and other pests there should be a good 'spring-cleaning' and the destruction of all filth in which it is likely to breed.

Insects have compound eyes consisting of many facets. Each eye of the house-fly contains 4000 facets, and so it has a wide angle of vision. Dragon-flies and hawk-moths have many more, whereas water insects have comparatively few.

House-flies breed very rapidly and would soon become a menace if not kept in check by:

(1) Human beings.

(2) Other animals. ("Will you walk into my parlour?" said the spider to the fly.)

(3) Parasitic enemies. Floating about in the atmosphere is a tiny plant called the fly-mould. Fine particles, or spores, settle on the fly's body and then send root-like fine hairs into the tissues of the fly. The fly becomes too weak to search for food and dies. The fly-mould is an instance of a parasite (see Chapter XXII), the fly being the host which provides food.

It is interesting to study the life-history of the house-fly. The fly lays about 150 eggs on warm soft refuse. In a day or two they are hatched out as grubs or maggots. They have no limbs but their food is at hand. In less than a week they reach full size and are then known as pupæ. After a week's fast they become full-grown flies with wings, etc. They are known as 'imagos.' If the season is too late for them to survive they remain in the pupa stage until the spring.

There are male and female flies.

Butterflies. In summer-time plenty of butterflies are obtainable, and their life-history should be studied. The cabbage-white butterfly may be killed and examined. The main facts relating to the butterfly are:

(1) They exist in a great number of varieties of colours and sizes. Their wings are covered with a fine dust or scales.

(2) Like all other insects they consist of head, thorax, and abdomen. They have three pairs of jointed legs

and two pairs of wings, all on the thorax. They have two large compound-eyes, each containing many facets, two antennæ, and a sucking-tube, or proboscis.

(3) There are male and female butterflies, which can be distinguished by special wing markings.

(4) The life-history of the butterfly is very similar to that of the house-fly as far as the stages are concerned. Eggs are laid by the female butterfly near a food supply. When hatched they are called larvæ, or caterpillars. Examine a few. They have enormous appetites and their skins become so tight that they burst them. Fortunately a new one has been preparing, which will enable them to grow still larger. The skin bursts several times before they are full-grown. Then they hang by their tails to some object and spin a silken girdle or covering. In time this splits and drops off and a fluid encases them, which sets hard into a transparent shell. It is now a pupa, or chrysalis (from the Greek word for gold, because the pupæ of some insects are like gold). In summer the pupa remains in this condition for two or three weeks; but an autumn pupa will remain in this stage until spring. Finally the covering splits and the imago or butterfly emerges.

The butterfly is kept in check by:

(1) Man.

(2) Other animals, like birds.

(3) Parasites. The parasite in this case is the ichneumon-fly, and the caterpillar is killed as follows. When the butterfly lays her eggs the ichneumon-fly carefully examines them, and, having selected eggs which are found to be fertile, she lays her own eggs inside. The

> larvæ of the butterfly and the ichneumon-fly develop side by side, the larvæ of the latter feeding on the blood of the caterpillar. They do not injure any vital parts of the caterpillar, but they suck its blood, and just when the latter has reached the chrysalis stage it becomes limp and weak, and dies a victim to the parasite. The larvæ make a hasty exit from the dying host, as many as twenty to sixty emerging from one caterpillar.

Thus we have another instance of how the 'balance of nature' is maintained.

Some insects have gained notoriety for their terrible toll of the human race—*e.g.*, the mosquito, several species of which occur in the British Isles, where they are called gnats. The connexion between mosquitoes and malaria is now well known, mainly owing to the work of Major Ronald Ross. Malaria is a fever common in Southern Europe, Asia, Africa, and America. The death-rate is high, and those who survive suffer to the end of their days. It has been called the 'destroyer of the human race.' The common remedy is quinine, obtained from Peruvian Bark or cinchona. It was not until 1880 that a French doctor detected the micro-organism which causes the disease in the blood-stream of a malaria patient. How did this micro-organism get there? Probably from the mosquito in the act of biting a person.

For many years Ross carried on the search. He fed hundreds of mosquitoes on the blood of malaria patients, then killed them and searched their bodies for evidence of the organism. At last he was able to show

that certain mosquitoes, living on the blood of malaria patients, became infected with this organism, and on biting another person passed the disease germs to him. They rapidly multiply in the human body, giving rise to malaria. As these insects are active only at night-time, residents in malaria districts can escape the disease by sleeping in mosquito-proof rooms.

The life history of the mosquito is now well known. Eggs are laid in stagnant water, swamps, etc., and the larvæ and pupæ are both developed in water. The covering of the pupa splits and the perfect imago then emerges. After a few seconds in which it becomes acclimatized to, and hardened in, the atmosphere, it flies away and begins its deadly work.

The best way of getting rid of malaria is to get rid of mosquitoes by destroying their breeding-places. The larvæ come to the surface to breathe, and a thin film of oil spread over the surface of stagnant waters prevents them breathing. Now marshes are drained and covered with a film of paraffin oil, and in this way large districts have been made habitable.

During the first eight years of the construction of the Panama Canal over 16,000 workmen lost their lives through the mosquito, which caused the abandonment of this great engineering work. Later, when medical research had discovered the true connexion between mosquitoes and malaria, the district was cleansed of the insects and the canal was completed.

In cases of insect bites the first step to be taken is to paint the wound with iodine, as there is always a possibility that germs may be introduced into the blood-stream. Stings in the throat, and near the eye and mouth, should be treated by a doctor.

Most insect stings are formic-acid stings, and to counteract them and relieve the pain some alkaline solution should be used. Therefore, after iodine has been applied, wash the spot with a solution of soda, potassium permanganate, limewater, or ammonia.

A bee sting is an alkaline sting, so vinegar or a weak solution of any acid may be used. Wasps are a great nuisance, and as they are constantly alighting on food there is a danger that one may be swallowed or taken into the mouth. Until a doctor can give proper treatment a raw onion is considered to be the best remedy, as it yields a large amount of juice when it is chewed and so checks the pain and prevents swelling.

EXERCISES

1. Kill several insects—flies, bees, butterflies, etc. Draw them and show the head, thorax, abdomen, legs, feelers, or antennæ, and wings. Compare with a spider.

2. Count the number of segments in both the thorax and the abdomen. Can you see the breathing-pores? Are there any appendages on the abdomen?

3. Draw the legs of several different insects, showing the joints.

4. Search leaves, twigs, buds, etc., for eggs of the caterpillar. How are they arranged, singly, in rows, or in clusters? What colour are they? Hatch some.

5. Observe a caterpillar. Describe its colour, size, degree of hairiness, food, and behaviour when touched. Can you detect it changing its skin? How does it eat a leaf, by cutting it out or eating the surface?

6. Examine a cocoon. Keep a few in a box or glass jar with soil, plants, or leaves in it. How long does the caterpillar stay in this stage?

7. Side by side with the development of the caterpillar study the development of frog spawn, and the hatching of birds' eggs.

8. Look up in an encyclopædia the following words: ague, malaria, sleeping-sickness, host, parasite, mosquito, house-fly, clothes-moth, bee, wasp.

9. Write an account of the construction of the Panama Canal.

CHAPTER XXVII

SOLITARY, SOCIABLE, AND SOCIAL (OR COMMUNAL) ANIMALS

Some animals live very solitary lives. Earthworms and snails are hermaphrodite—*i.e.*, each worm or snail acts both as a male and a female, laying eggs and producing the substance which makes the eggs fertile. They can live alone; they are complete in themselves.

The house-fly and the bee are only capable of exercising one of these functions. If it can lay eggs it is a female; if it cannot lay eggs but can produce the material which will fertilize the eggs it is a male. In most species of animals there are two sexes, generally designated by special names. For example:

Animal	Female	Male
Bee	Queen	Drone
Fowl	Hen	Cock
Duck	Duck	Drake
Cattle	Cow	Bull
Horse	Mare	Stallion
Rabbit	Doe	Buck

There are solitary bees, consisting only of males and females, and they live in pairs. Even where several pairs of such animals live together they do not work together like the honey-bee, but 'mind their own business.' Examples of solitary bees are the osmia and the sleeper bees.

The osmia bee bores a hole in a rotten stump and

builds her nest at the bottom of it. She next builds a waxen cell, lays an egg in it, leaves a supply of bee-bread, and seals up the cell with wax. The whole passage is built up with such cells. All the grubs become perfect bees at about the same time, and the bee in the bottom cell has to wait until the others in the cells above it get out of the way.

The sleeper bee is often found asleep in flowers. She burrows in posts, thatched roofs, etc.

Sociable Animals. Many animals live together in groups or colonies, either because they were produced in large litters or because there is a sufficient food supply for a large colony. Such animals include rabbits, pigeons, and wolves. They may have little or nothing in common; they live together in harmony merely because there is no reason why they should quarrel with each other, that is, as long as they have sufficient food. They may be able to communicate with each other; at least they can utter interjections which signify the discovery of food or the approach of danger. A wild horse or cow warned of the approach of danger, either by smelling the scent of the enemy or by hearing some noise at hand, runs off as quickly as possible; the other members of the herd, seeing or hearing the alarm, quickly follow. A rabbit, sensing danger, runs away with its white tail cocked in the air; the others, quick of sight and hearing, quickly rush to their burrows. Such gregarious animals might be termed sociable animals. They 'live and let live.' They warn each other of danger, they play together, and if attacked may make a common stand against the enemy: usually they escape as fast as they can.

The lion is a solitary or non-herd animal, but wild

horses and cattle live in herds. The latter are ruminant or cud-chewing animals. Often they leave their young in a safe hiding-place while they gather food. They swallow it as they bite it, without masticating it, then retire to a safe place to chew the cud. They do this lying down, and if surprised and unable to escape rise on their back legs and offer the horns to the enemy. The horse does not chew its cud, but masticates its food as it eats it. When attacked it is ready to escape at once, as its young have long legs so as to be able to keep up with the parents. If surprised when resting it rises on its front legs and gets away quickly. Herd animals are not only quick of hearing but keen of sight, and, further, have a wide angle of vision as their eyes are on the sides of the head. Also they have movable ears which can be turned in different directions so as to be better able to pick up approaching sounds. In a fight the horse kicks out his back legs at the attacking enemy. Wild cattle, which cannot run as fast as horses, stand at bay and gore a lion or tiger and stamp it to death.

Casualties were probably very numerous, and the enemy captured the slowest-moving. The result of this age-long struggle between lions, tigers, etc., and the herd animals has been the improvement of the qualities of both species. Inefficient lions were unable to get food, and inefficient herd animals were caught, and both were weeded out, and prevented from breeding and passing on their inefficiency to their offspring. This explains why some animals, including members of the human family, have survived. So called primitive man and his contemporary animals bred from the strongest stock. The doctrine of the 'survival of the

fittest' should be renamed the 'destruction of the least fit.' Among the human race, the short-sighted, deaf, poor runners, poor jumpers, etc., perished first; so modern science which has produced better protective weapons has enabled a great many people to survive who would have succumbed in primitive times. 'Least fit' means least able to survive under existing conditions. A blind primitive man was easy prey, but the blind Milton survived until he died a natural death. It is sometimes claimed that war improves the quality of the race. So it might if two whole nations were to go to war—the inefficient and the physically unfit and the mental and moral weaklings would be thinned out probably more quickly than the rest. Unfortunately, in human warfare the contending armies consist of the most physically fit, and it is usually conceded that the race is impoverished as the result of each conflict.

Every animal seems to have its characteristic smell. We can smell rabbits, hares, dogs, mice, etc., when they are quite close to us; but other animals can smell danger at a considerable distance, especially when the wind is favourable. Some animals escape by mixing with a flock of other animals whose scent masks their own. The hare, for example, often escapes from dogs by going into the centre of a flock of sheep.

Social or Communal Animals. Some animals not only live together in a herd or colony but work together as a single unit, and they are called social or communal animals. It is too soon for you to decide which is the better system of organization, the sociable or the social, but examples of the latter are hive-bees, wasps, ants, beavers, etc. We may therefore classify animals according to their social organization as follows:

ANIMALS

- Solitary
  - *Hermaphrodite*
  - *Solitary pairs*
- Herd, flock, colony, etc.
  - *Sociable*
  - *Communal*

Hermaphrodite	*Solitary pairs*	*Sociable*	*Communal*
Earthworm Snail	Some bees Some wasps Hares (These exist in families and are more or less monogamous.)	Wild horses Rabbits Pigeons (This group includes many males and females. A large food-supply is available. Sometimes mutual defence is a feature of this life.)	Hive-bee Ant

The hive-bee is often put forward as an example for the human race to follow, but it differs so much in the organization of its life from other animals as almost to be called a freak animal.

A hive consists of from 20 to 50,000 insects, the grand object of their existence being apparently to lay up a store of food for the winter, their food being honey, which is nectar from flowers mingled with bee saliva. The hive, if natural, may be in holes in walls, banks, or trees. The bees first stop up all the cracks with propolis, a resinous substance compounded from vegetable sources such as bark and buds.

The inmates of a hive consist of:

(1) A queen (Fig. 182). It has a longer and slenderer body than the other members of the hive. It has short wings and a curved sting.

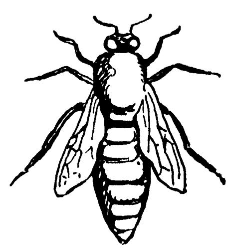

FIG. 182. QUEEN BEE

(2) The drones. These are males, and are without the defensive sting (Fig. 183).

(3) The workers. These number from 20 to nearly 50,000 per hive. They are the smallest members of the hive (Fig. 184).

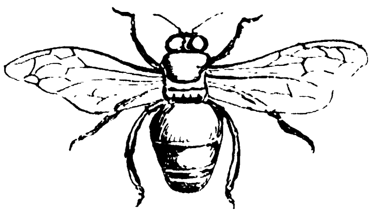

Fig. 183. The Drone

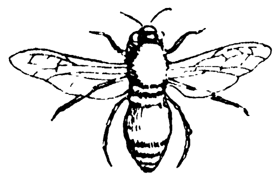

Fig. 184. The Worker

The worker bees build a honeycomb, consisting of numerous waxen hexagonal cells. There are three kinds of cells reserved for the queen, drones, and workers respectively. The workers' cells are the smallest, and some are used for storing honey.

The queen lays a large number of eggs each day. The fertilized ones yield females. In three days the queens hatch out as limbless grubs. The workers feed them solely on royal jelly. The larva or grub is then sealed up in a royal cell and in course of time passes through the stages of pupa and imago, or perfect insect. Only one queen is allowed to live in a hive; others, including visiting queens, are killed or expelled, ignored and allowed to starve, or they lead a swarm and found a new hive. The queen never leaves her hive except to swarm. During the three to six years that she lives her mission is to lay eggs. She does not make honey and she neither works for nor defends the hive. From the time the egg is laid fifteen days elapse before the queen bee becomes a perfect insect.

Workers are fed on royal jelly for only five days and then they are given another diet consisting of pollen and honey water. After being sealed up in their cells they pass through the pupa stage and in twenty-one days become perfect bees (workers). They are females but sterile, and they never (normally) lay eggs. They gather honey, and build and defend the hive. Usually they only live for from six to eight weeks, unless it is too late for them to emerge from the pupa stage, when they continue as pupæ throughout the winter. A few workers develop egg-laying propensities, but their eggs only give rise to drones.

Drones or males are hatched from unfertilized eggs in twenty-four days. They have the reputation of being lazy. They do not gather honey, but are useful because they fertilize the queen's eggs. When food is scarce they are the first to be sacrificed, being driven out of the hive and left to starve.

The worker is specially adapted for the purpose of gathering honey. On each hind-leg there is a pollen basket, and underneath a pollen brush. The pollen on one leg is rolled into a ball and put into the basket on the other leg. On entering a flower the brush removes pollen, which is then transferred to the basket in the manner already described. This is converted into bee-bread, which is given as food to the grubs.

In gathering honey the bee puts her proboscis into a flower and sucks up a little nectar. She passes this into her honey-bag (first stomach) and returns to the hive, where she is relieved of her burden by other worker-bees. Some of the honey is used as food for the grubs, but the rest goes towards the winter store in the honeycombs. As the bee-keepers take the honey they

have to replace it with a cheaper substitute in the form of syrup, or the bees could not survive the winter.

Some of the honey is converted into bees-wax. To do this the bee retains some honey, and hangs up by the front feet for about twenty-four hours. By some mysterious digestive process the honey becomes bees-wax and oozes from her body into eight receptacles or pockets on the underside of her body. She works this in her mouth and uses the product as a building material.

Observers of bees claim that the whole hive is working to a plan; some bees ventilate the hive, some wait on the queen, some clear the hive and throw out dead bodies, the queen lays the eggs, the drones fertilize them, and the majority, the workers, gather and store food.

Their activities are of great benefit to the human race. They supply us with honey and bees-wax, and these could be enormously increased if more hives were dotted about our gardens, parks, orchards, heaths. Moreover, the fruit supply would benefit. Their visits to flowers bring about cross-fertilization, thus leading to new and hardier plants. It appears that bees do not make haphazard visits to flowers but go from apple-tree to apple-tree on one journey, then, say, from primrose to primrose on another, and so more certainly bring about cross-pollination. They apparently do not mix varieties of plants in the same tour.

When the bee thinks that she is in danger she stings, but as the sting of the worker is barbed it cannot be pulled out, with the result that it is torn from her body and she goes home to die. The wasp's sting is not barbed and it can be used again and again.

In time a hive gets crowded with all the young bees, and a swarm consisting of a queen and thousands of workers leave the old hive and found a new one. The bee-keeper makes early preparation for this event, and the swarm is caught before it wanders away from the garden. There must be in each hive a queen, some drones, and thousands of workers.

CHAPTER XXVIII

NATURE-STUDY

THE best way to extend your knowledge of nature is to visit the country, the forests, meadows, and streams, and see animals and plants in their natural surroundings. If this is not possible, visit parks, a zoo, farms, the school garden, an aviary, a hen pen, a duckpond. If these are not accessible hundreds of plants can be grown in plant-pots in school and at home, and frog spawn, for example, can be kept in a glass jar until the tadpoles are well developed, when the water should be poured into a shallow dish so that the frogs may pass on to dry ground. A ranarium, an aquarium, a pond, and an aviary are quite within the capacity of most schools. Tortoises and rabbits, pheasants, pigeons, and doves, and caged birds such as canaries and budgerigars can be kept and reared, and they will serve as representatives of some of the more important families of living things.

Examine the plants that you see when on a country walk. Some are small plants (like the daisy and buttercup), others are termed bushes or shrubs (like the gooseberry bush), others are classed as trees. It is an arbitrary division but a convenient one. Some plants are annuals, that is, they complete their life-history from seed to seed in one year—*e.g.*, the snapdragon—others are biennials, and yet others are perennials.

If you call at a nursery you may see a gardener at work, perhaps pruning. He is not cutting off branches

or roots in any haphazard way, but he is shaping the tree or the shrub in a scientific manner. In the case of the marguerite, the raspberry, and loganberry his pruning is simple, for his main work is to cut off last year's dead wood or stalks; the new flowers, or canes, will come without much further attention. In the case of roses he cuts back the old growth pretty severely, making his cuts at buds which are pointing outward, so that the centre of the bush is open to the air and light (Fig. 185).

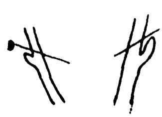

FIG. 185

Fruit-trees are grown "to bring forth much fruit," and it is surprising how light and air contribute to this end. The tree is given a good shape, dead wood is always removed, and the centre is kept open so that light and air can enter. The branches are then pruned, as in the case of roses, to a bud that grows outward (Fig. 186).

On looking round the garden you notice evergreens and deciduous trees, the difference in colour, smell, texture, arrangement of leaves on the stems of plants, the flowering and the flowerless plants, and plants with protective devices like hairs and thorns. You may see a gardener planting his potatoes in rows leading from north to south so that they will get the maximum amount of light. Notice how deeply he plants them. He does not always propagate his plants by sowing seeds. He makes a great many cuttings of several plants, including geraniums, chrysanthemums, and antirrhinums. He removes a portion of stem from a full-grown plant, trims it with a sharp knife or a pair of pruners just below a joint,

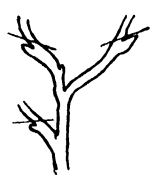

FIG. 186

pulls off the leaves except those near the top, and inserts it in a sandy soil. In a few weeks a new plant has rooted (Fig. 187).

Such cuttings can be rooted in the form room or laboratory, and the supply of plants readily increased.

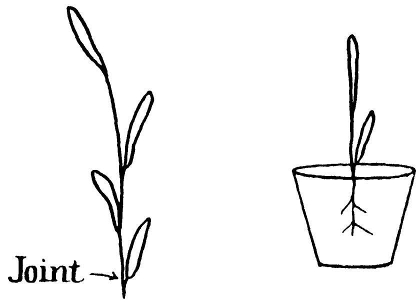

FIG. 187

Try to reason out if plants made from cuttings will tend to have scented or scentless flowers.

You are likely to see many birds on a country walk, and such particulars as the following should be looked for:

(1) Their size. There are wide extremes—*e.g.*, the wren and the eagle.

(2) Their shape. Compare the pigeon and the duck.

(3) Their bearing. People refer to the cheeky robin and sparrow.

(4) Their song. Compare the chirping of the sparrow, the cooing of the dove and pigeon, and the joyous trills of the lark. The starling can imitate them all.

(5) Their plumage. Note the black plumage of the rook and crow, the mottled breast of the thrush, and the redbreast of the robin. Also compare the feathers of a water-bird—*e.g.*, the duck—with the feathers of a hen.

(6) The shape of the beak. You will notice great varieties of beaks.

(*a*) Some birds are grain-eaters and have thick, short beaks—*e.g.*, the sparrow and the pigeon (Fig. 188).

FIG. 188

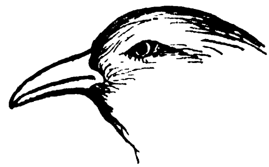

FIG. 189

(*b*) The insect-eater has a longer and thinner beak (Fig. 189).

(*c*) Crows, kingfishers, herons, etc., have a dagger-like beak (Fig. 190).

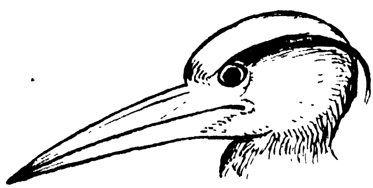

FIG. 190

(*d*) Parrots have a nut-cracker beak (Fig. 191).

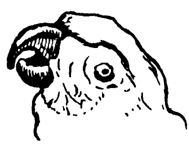

FIG. 191

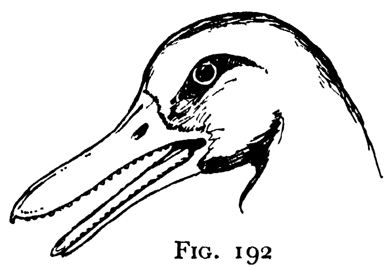

FIG. 192

(*e*) Ducks have a strainer-beak, which allows mud and water to drain away as they feel for their catch (Fig. 192).

(7) The legs and toes. The feet of birds are also specialized. Birds are usually four-toed, and they walk on their toes, which are clawed. Some birds are perchers, and usually perch with three toes in front of the perch and one behind (Fig. 193). Owls perch with two toes in front and two behind.

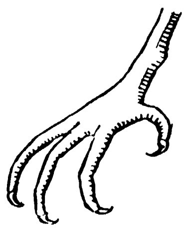

FIG. 193

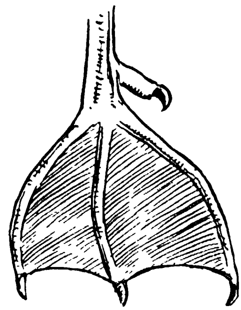

FIG. 194

Ducks' bodies are not the right shape for perching. Their feet are also webbed, showing that they are swimmers (Fig. 194).

Birds that wade have not only long legs, but the toes can be extended over a wide base for greater stability in the mud (Fig. 195).

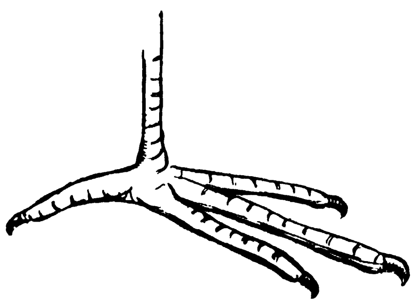

FIG. 195

Just as you remembered broom and gorse by their differences, so the carrion crow and the rook need not

be mistaken for each other if you are in a position to observe them closely. They are practically the same size, but the crow has a stouter bill than the rook and it has feathers on the beak near the base, whereas the rook has a bare white patch (Fig. 196).

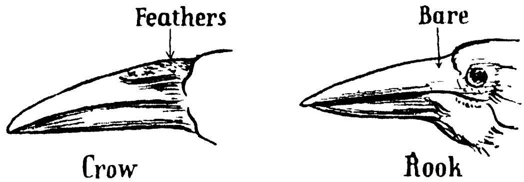

FIG. 196

There are, at the most, only eight members of the crow family in Britain, and they should be studied together. They are: (i) the raven, (ii) the carrion-crow, (iii) the hooded-crow, (iv) the rook, (v) the jackdaw, (vi) the magpie, (vii) the jay, and (viii) the chough.

There are many other small groups of animals which might be studied together—*e.g.*, the reptiles. There are only six species of reptiles found in Britain, namely, three lizards and three snakes. They are as follows: (i) the common lizard, (ii) the sand lizard, (iii) the slow-worm (a limbless lizard), (iv) the adder or viper, (v) the grass-snake, and (vi) the smooth snake.

The egg is worthy of special attention. You will notice the size of all eggs you come across, the markings on them, their shape—compare the pointed eggs laid on rocky ledges with the more rounded eggs laid in the nest. Do not take the eggs. A hen's egg, when carefully cracked and drained into a dish, is seen to consist of an outer shell, with a membraneous lining, and a yolk floating in a mass of almost colourless

albumen. Notice the spot where it has been fertilized, and the balancers.

A cow will serve as a standard with which to compare other animals. Notice:

(1) Its covering of hair.

(2) Its horns for defence, and the way it rises from the ground.

(3) That it is a herd animal.

(4) The use it makes of its tail to remove flies from its body and to get rid of amateur milkmen.

(5) How it swallows the grass and then lies down to chew the cud. Note the sideways movement of the jaws to assist it in grinding its food.

(6) The position of its eyes so as to give it a wider range of vision.

(7) That it is a mammal, because it suckles its young—the milk we drink was intended for its young, but after domesticating the cow man found cheaper food than milk to give the calf, or he killed the calf for his own food.

(8) Corresponding features in the cow, horse, and human beings. Remember man is supposed to have been evolved from a quadruped. Examine the back leg of a quadruped and find its knee and heel (Fig. 197). The cow and the horse walk on the tips of their toes, which have become protected with a thick toe-nail or hoof.

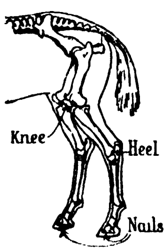

FIG. 197

As there are thousands of different kinds of animals in the world, every journey into the country ought to be rewarded with some new discovery.

EXERCISES

1. Compare the legs, feet, and tails of a horse and a cow.

(*a*) Draw the tails, showing where the 'flesh and blood' end and the hair begins.

(*b*) How many toes have they on their front and back legs?

(*c*) How do they remove insects, etc., from the body?

(*d*) Of what use is a horse's tail, and why is it usually docked?

2. How do the horse, cow, dog, cat, sheep, and pig rise from the resting position, and how do they lie down?

3. Draw an oval to represent the face of a cat, dog, cow, pig, sheep, and horse, and show where the eyes, ears, and horns (if any) are.

4. Which birds are resident in your district all the year round? Draw their outlines.

5. Which are migratory? Draw them.

6. Make a list of birds that you observe, and say which are hoppers, walkers, and flying birds.

7. Examine the toes of as many birds as you can. How do they perch? Are any swimmers or waders?

8. Examine some nests, stating where they are found, the materials of which they are made, and the number of eggs found in them. State when the eggs are laid, and specify their shape and markings.

9. Take an old nest and break it to pieces to see of what it is composed.

10. Examine a sparrow, thrush, and robin. Are they grain-eaters or insect eaters?

11. Make a large circle to represent an area round your school or home. Show the north and south line. Indicate by marks on the drawing where the chief crops are grown, the position of the nests you have found, the pond from which you have got frog spawn, and any other features of biological interest.

CHAPTER XXIX

UPSETTING THE BALANCE OF NATURE

In Chapter XXII several instances were given of interdependence in nature, which resulted in what has been termed a 'balance in nature.' Carbon dioxide, one of the products of respiration and combustion is, fortunately for all living things, gaseous at the ordinary temperature. It passes into the atmosphere and is assimilated by green plants in the presence of sunlight. The carbon is retained and the oxygen is set free, with the result that the percentage of carbon dioxide is maintained at approximately ·03 per cent. If carbon dioxide had been a solid compound the amount of oxygen would gradually have been reduced, and possibly by this time the atmosphere would have been incapable of sustaining life. Owing to its low melting-point carbon dioxide will never be solidified in the atmosphere during the period that life can subsist on the earth.

Too often instead of co-operation there is war between two species of living things; the balance is upset and serious consequences ensue. Disease is generally due to microbes entering the blood-stream through a wound. They multiply so rapidly that the white corpuscles—the policemen of the blood—are overwhelmed, and the person becomes ill. Plague, malaria, typhoid, influenza, and other diseases have wrought havoc in the past, but medical research is slowly providing means to combat and prevent them.

The word 'pest' is a shortened form of 'pestilence,' which was formerly applied to any contagious deadly disease (Latin *pestis*, a contagious disease). It is now applied to anything destructive, and even to a troublesome person. Living organisms with unhealthy habits —*i.e.*, habits which clash with the habits and interests of higher organisms—often breed so fast as to become a nuisance and even a danger. The mosquito is a pest, and in the past rendered large areas uninhabitable. The pests generally referred to are animal pests, but there is no reason why plants should not be included in this category.

Weeds are plants which come without being planted. Sometimes the seeds of weeds are mixed with good seed when it is purchased. Seedsmen cannot always guarantee 100 per cent. purity of seed, and the law only requires them to guarantee a certain minimum of 'good seed'—*i.e.*, seed true to description. Seeds of different plants are blown about and spring up many miles away from their point of origin. So long as they are not very numerous no great harm is done. Poppies appear in the cornfield; mustard is a common weed; yarrow flourishes in badly cultivated and ill-nourished soils; reeds and rushes occur near ponds; groundsel, thistles, coltsfoot, or cleat, and docks spring up in the garden. Sometimes an enterprising person finds a use for weeds—*e.g.*, coltsfoot is used in making wine and is put into sweets. If we could only find uses for all pests we should succeed in keeping them under control. As it is impossible to pull up every weed the farmer has developed a system known as control. Crops are grown which will smother the weeds, or the land is so cultivated that the weeds cannot survive under the new

conditions. The keynote of the policy is: "Cultivate the ground well, give the land plenty of plant-food, and sow good seed." The conditions prescribed by this policy are inimical to the growth of weeds.

Flies—the ordinary house-fly, bluebottles, etc.—wasps, and locusts may become pests, and the only safe and sure remedy is to destroy their breeding-places if possible. Clear away and burn useless rubbish. Some of these pests may resist the fumes of poisonous gases, such as sulphur dioxide and formalin, which would certainly kill human beings.

Most townspeople regard rabbits as an asset to the countryside. But, formerly unknown in Australia, they were introduced by the early settlers and have bred to such an extent that they have become a serious pest, and do much damage to crops. Although they have been killed by the million and exported for food, they still continue to flourish, and the Australian Government would give a handsome reward to anyone who could free Australia from this pest.

One of the problems that a farmer has to decide is which birds he should not molest and which he should shoot—*i.e.*, which are allies, killing insects, wireworms, slugs, etc., and which destroy his crops? Some birds, while they eat a little grain, feed more largely on pests. The farmer finds the answer to his question by doing a little experiment. He shoots a number of birds, examines their crops to see what they eat, and thus determines which birds to kill and which to protect. Birds with thin beaks are mostly insect feeders, and those with thick beaks, like sparrows and finches, are mostly grain eaters. A partridge shot in November, 1932, contained in its crop 520 shoots of

wheat, 40 shoots of oats, 7 leaves of clover, 420 wild oats, and 8 seeds of stone-weed, a total of 997. We read in *Farm Insects*, by John Curtis (1883), of a cock-pheasant killed in December, 1844, which had 852 tipula grubs (leather-jackets) alive in its crop. A hen pheasant was once killed that had 1225 live wireworm grubs in it, suggesting that this was one meal. Rooks eat up large numbers of wireworms, cockchafer larvæ, and other grubs.

In some parts of the country bird censuses have recently been attempted. A rook census was taken in Nottinghamshire, Leicestershire, Derbyshire, Rutlandshire, and Lincolnshire, and it was found that there were 1421 rookeries and 128,266 rooks in an area of 5305 square miles. It was estimated that they ate 4008 tons of the farmers' crops every year. This census was not so difficult as it may appear at first sight. The nests were first counted, and multiplied by two to arrive at the number of April rooks, and then by six to calculate the number of May rooks. (Why multiply by two and six?) Rooks cling tenaciously to their old haunts.

> Often they withstand great persecution; often they see their trees decay, and fall from year to year; they suffer hardship from food shortage owing to the altered state of the land, but they remain faithful to the ancestral domain.[1]

Recently zoologists have attempted censuses of different animals. For such a piece of research hundreds of observers in different parts of the country are necessary. The counting of starlings was very

[1] Report by Mr A. Roebuck to the Zoological Section of the British Association.

difficult as this bird is, next to the sparrow, the most numerous. Some birds are caught and then ringed before they are again set free. When they are next caught, or after they have been shot, particulars are sent to a central station. Thus the movement of birds can be followed. The Baltic starling migrates to the British Isles for the winter.

Other zoologists have tried to estimate the number of rats, squirrels, mice, shrews, etc., in successive years. It is believed that each species of animal increases in numbers to a peak of population and then is attacked by some malady which wipes out great numbers of them and checks their increase. Squirrels, it is believed, become most numerous every fourth year and then the malady reduces their ranks. The English red squirrel has been declining in numbers since the grey squirrel was deliberately introduced to add to the beauty and variety of our countryside. Unfortunately, the grey variety has flourished at the expense of the red variety, which has either been killed or expelled from its former haunts. In other words the grey squirrel has become a pest. The year 1931 witnessed a remarkable decline in the number of grey squirrels throughout the British Isles. Apparently some disease had spread among them with the force of an epidemic, and the red squirrels had a chance to recover their lost ground.

Other observers have shown that the greater-crested grebe has been steadily multiplying throughout the Norfolk Broads; but, on the other hand, that magnificent hawk, the kite, is becoming extinct. There is a Royal Society for the Protection of Wild Birds. Bird Sanctuaries have been established, and penalties are

imposed on egg-stealers who are willing to sacrifice beauty and rarity for personal gain.

Winter is another check to the increase in the number of birds. After a severe frost, when food and water are difficult to obtain, thousands of birds and other animals perish. Many birds are big eaters, and they the more readily die.

One of the most dangerous pests is the rat, which does between 50 and 100 million pounds worth of damage in this country alone. There are now three species of rats in this country, namely, the black rat, the grey or brown rat, and the musk rat. The black rat is known as the British rat, the grey rat as the Asiatic rat, and the musk rat, like the grey squirrel which has also become a pest, was introduced deliberately. The smaller black rat has become rarer in most parts of the country as the grey rat, a larger variety, has become ubiquitous. A few years ago the musk rat, or musquash, was introduced to Britain and the continent to be bred for its fur. Some escaped and others were set free, and thereupon they began to breed at an incredible rate. It is estimated that from five introduced into Europe in 1905 there are about 100 millions of descendants. This rat is described as clean in its habits, licking its food clean before eating it; but it is a pest. It builds picturesque three-roomed homes which stand up like hives in the centre of ponds and rivers. It has some commercial value as its skin is converted into musquash coats. But this does not compensate for the great damage it does. It burrows incessantly, undermining railway, river, and canal banks, and bridges. In Great Britain they became numerous in Shropshire and along the Severn, and

penetrated counties as far apart as Perthshire and Kent. They are easily recognized, as they are larger than the ordinary rat and have an oar-like long tail and partially webbed feet with naked soles. Their burrows are almost hidden from sight, and the first intimation of their presence is the collapse of a bridge or the leaking of a canal.

Whether the pest be sparrow, rat, wasp, mosquito, ant, locust, or rabbit, etc., it may be described either as a nuisance, a danger to health, or a destroyer of hard-earned wealth. Some pests, like the rat, may be all three. It has spread disease and destruction throughout the world and has not a single defender. The Black Death, which carried off about one-fourth of the population of this country in the fourteenth century and large numbers at other times—*e.g.*, in 1665, the year before the great Fire of London—was caused by the rat carrying disease-spreading vermin which bit people, giving them the plague.

Pests are kept in check by various methods, some natural and others human. The natural checks are:

(1) **Enemies.** Animals eat other animals for food. If all had sufficient they might tolerate each other. Many animals seem very slow in modifying their diet, and if they cannot get their natural food they perish in the midst of plenty. Gardeners regard ladybirds, which eat aphides and other insects, frogs and toads, which eat slugs, and certain birds that eat caterpillars, snails, and worms, as their allies.

(2) **Disease.** This has already been referred to.

(3) **Food.** An increase in the number of any pest may cause insufficiency. Frost may lock up food and water, when big eaters die in large numbers. Some

birds guard against this possibility by migration to southern countries in winter and to northern countries in summer. It is rather a curious fact that the birds that leave England in spring must leave enough food behind for our own summer visitors, possibly a different kind of food.

One question not satisfactorily explained is, "Do pests come because there is a food supply of filth and waste that no other animal will touch, or do they simply come in accordance with some yet unknown law, and subsist on the food they find? Are weeds and insect pests in possession of their habitat because they have displaced some other plant or animal, or are they there because Nature has provided in them organisms which find these conditions ideal?"

The human checks are:

(1) **Destruction of Pests and their Breeding-places.** *E.g.*, washing the hair, cleaning carpets, draining marshes, etc.

(2) **Control.** In the course of thousands of years farmers have discovered how to treat the soil to get rid of various diseases and pests. Some crops require much lime, and insufficiency causes diseases like club-root or finger-and-toe among the cabbage family; but the presence of lime may cause a disease among potatoes known as 'scab,' and render the soil unsuitable for growing rhododendrons. There are thousands of acres of land in the British Isles which were once fertile, but which have become derelict through being short of lime, which could be supplied in the form of quick-lime, or slaked lime, chalk, or limestone.

Lastly, plants and animals are carefully studied from different aspects: their origin, growth, and develop-

ment; how they respond to different treatments; how they feed and breed; how new species can be produced, etc. In this way the range of species has been increased, plants have been made immune to certain diseases, the principle of rotation of crops has been extended, finer crops have been marketed, the supply of foodstuffs has been enormously increased, and man may be said to have gained "dominion over the fish of the sea, and over the fowl of the air, and over the cattle, and over all the earth, and over every creeping thing that creepeth upon the earth." (Genesis I, 26.)

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